

NS 1.2. AW 1/976

COMPUTER SCIENCE SECTION

SUMMARY OF AWARDS

**Fiscal Year 1976
and the Transition Quarter**



NATIONAL SCIENCE FOUNDATION
ASSISTANT DIRECTOR FOR
MATHEMATICAL AND PHYSICAL SCIENCES, AND ENGINEERING
DIVISION OF MATHEMATICAL AND COMPUTER SCIENCES
Computer Science Section
Washington, D.C. 20550

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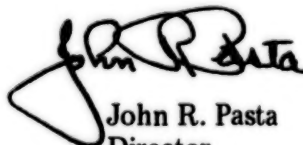
PREFACE

The purpose of this report is to provide the scientific community with a summary of those grants awarded by the Computer Science Section of the Division of Mathematical and Computer Sciences in fiscal year 1976 and the Transition Quarter.* The report lists fewer than the actual number of projects currently receiving support because the duration of many grants exceeds one year.

Similar areas of research are grouped together for reader convenience. The reader is cautioned, however, not to assume these categories represent either the totality of interests of each program or the total scope of each grant. Projects may bridge several programs or deal with topics not explicitly mentioned herein. Thus, these categories have been assigned administratively and for the purposes of this report only.

In this document, grantee institutions and principal investigators are identified first. Award identification numbers, award amounts, and award durations are enumerated after the individual project titles. Within each category, awards are listed alphabetically by institution.

Readers wishing further information on any particular project described in this report are advised to contact principal investigators directly or the Computer Science Section.



John R. Pasta
Director
Division of Mathematical and
Computer Sciences

*Effective October 1, 1976, fiscal years no longer begin on July 1. Therefore, "transition quarter" referred to herein is for the period July 1, 1976, through September 30, 1976.

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INTRODUCTION

The Computer Science Section of the Division of Mathematical and Computer Sciences awards grants to support research in computer science, computer engineering, and computer applications. Topics of interest to the Section include, but are not limited to, the following:

Theoretical Computer Science Program—This program supports basic research in the theory of computation, numerical analysis and computational mathematics, theory of formal languages, intelligent systems, and other topics concerned with the theoretical foundations of computer science.

Software and Programming Systems Program—Awards in this program support basic research on software and systems of programs, including operating systems, computer languages and their processors, information structures and file management, proof of program correctness, and the study of algorithms.

Computer Systems Design Program—Grants in this program focus on the development of principles of computer systems design, including computer system architecture, computer system performance, major subsystems, and logic design.

Techniques and Systems Program—Awards are made in this program for projects to develop new computer-based methodologies for research. Projects include advances in interactive techniques, on-line and real-time systems, hierarchical computing, and other applications of recent developments in computer and communication technology. Proposals are examined critically in this program to assess the potential contribution of the proposed work to research in the intended area of application.

Networking for Science Program—NSF awards in this program support research and special studies to explore the resource-sharing potential of computer networking for science research and education. This program is coordinated with related activities of the Office of Science Information Service. Issues include specialized resources, user functions, organization aspects, economic implications, network technology, and evaluative activities. Further emphases include mathematical studies in the structure and functioning of networks as well as analyses of networking problems comparatively specific to the needs of particular scientific disciplines and research areas.

Software Quality Research Program—Research and development activities are directed at providing researchers with accurate, consistent, well-documented, and extensively tested software. Strong emphasis is placed on considerations of software analysis, robustness, performance, validation, and related topics. In addition, special encouragement is given to projects to develop improved approaches to portability, availability, and distribution of computer software applicable to research.

Special Projects Program—This program awards grants for research projects, studies, workshops, and other activities which encourage the development of new fields of computer science research that are responsive to the problems and opportunities arising from the widespread use of the

computer in the service of society. Topics include, but are not limited to, technical questions of privacy in computer systems, human/machine interface, the state of computer science research, the concepts underlying computer simulation and conferencing, and the structure and control of very large data bases.

ELIGIBILITY

Guidelines on eligibility and proposal preparation and other helpful suggestions are contained in the NSF brochure *Grants for Scientific Research*, #NSF 76-38, which may be obtained from the Foundation.

While universities can be expected to be the primary recipients of support in the above-named programs, industry and other organizations are eligible for support. Unsolicited proposals will be accepted from any source, subject to cost-sharing requirements. Proposals will be solicited as necessary in certain areas. Awards resulting from solicited proposals may provide full costs, with cost-sharing or fees negotiated as appropriate.

Deadlines—Proposals may be submitted at any time.

Additional Information—Communications may be addressed to:

Computer Science Section
Division of Mathematical and
Computer Sciences
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

SUMMARY

	<i>Number of Awards</i>	<i>Value of Awards</i>
Theoretical Computer Science		
Theory of Algorithms	15	762,900
Theory of Computation	14	538,300
Intelligent Systems	14	584,100
Numerical Analysis and Computational Mathematics	21	581,600
Augmentative Theoretical Studies	13	620,700
Studies and Colloquia	2	17,600
Software and Programming Systems		
Programming Languages and Compilers	11	915,100
Operating Systems	8	824,600
Information Retrieval	4	224,100
Formal Structure of Programs	8	602,100
Symbolic and Algebraic Manipulation	5	170,300
Program Verification	2	242,000
Computer Systems Design		
Computer System Architecture	13	1,182,300
Fault Tolerance and Reliability	2	266,800
Computer System Performance Measurement and Evaluation	3	135,600
Graphics and Input/Output Research	2	336,900
Logic Design and Major Subsystems	1	71,300
Other	1	8,600
Techniques and Systems		
Data Acquisition and Analysis	6	356,300
Graphics Techniques	7	880,200
Hierarchical Systems	1	74,500
Modeling	6	522,800
Machine Intelligence in Research	15	1,250,500
Studies and Colloquia	2	8,100
Networking for Science	7	546,600
Software Quality Research	40	1,570,800
Special Projects		
Modeling	9	508,000
Privacy and Security	11	478,700
Human/Machine Interface	6	359,500
Studies and Colloquia	7	238,100
Data Bases	4	211,800
Networking	2	41,700

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THEORETICAL COMPUTER SCIENCE

Theory of Algorithms

Brown University; John E. Savage; Analysis of Algorithms and Data Structures; (MCS 7620023); \$70,000; 24 mos. (TQ)

The goal of this research is to acquire a deeper understanding of the limitations on the performance of computers. Achievement of this goal will be attempted by:

1. Studying concrete measures of the inherent complexity of functions, such as combinational complexity and synchronous combinational complexity;
2. Deriving good lower bounds to the complexity of important problems;
3. Relating these measures to important measures of computation;
4. Studying data structures and algorithms which lead to effective spacetime tradeoffs on realistic computer models.

Brown University; Robert Sedgewick; Analysis of Heapsort; (MCS 7523738); \$27,200; 24 mos.

The project involves a detailed analysis of Heapsort, analogous to the work that has been done on Quicksort. The object of the analysis is the derivation of exact expressions for the average (and other moments); best case, and worst case time and space requirements of typical implementations of the algorithm and its variants.

University of California (Berkeley); R. M. Karp; Computational Complexity and the Analysis of Algorithms; (MCS 7417680A02); \$35,500; 12 mos.

The objective of this research is to place on a sound theoretical footing the study of heuristic and approximate algorithms for hard combinatorial optimization problems. Examples of such problems are the determination of maximum cliques, minimum colorings and minimum-cost tours in graphs.

This is the third year of a 3-year continuing grant.

University of California (Berkeley); E. L. Lawler; Research in Combinatorial Algorithms; (MCS 7617605); \$57,300; 24 mos. (TQ)

This research is concerned with combinatorial algorithms, particularly algorithms for solving machine sequencing problems and combinatorial optimization problems over graphs, networks, and matroids. Specific topics to be investigated include the classification of sequencing problems according to complexity; development of algorithms for machine sequencing, graph coloring, the analysis of series parallel digraphs, the weighted matching problem, and the matroid parity problem; and the application of subgradient optimization techniques to the job shop scheduling problem, the traveling salesman problem, and the matroid parity problem.

University of California (La Jolla); Michael L. Fredman; Analysis and Development of Data Structures for Storage, Manipulation, and Retrieval of Computer Data; (MCS 7608543); \$36,000; 24 mos.

The purpose of this project is to discover unifying methods and principles to aid in the further development of new data structures, and to further the improvement and analysis of existing types of data structures. This is to be accomplished by developing models or formats for data structures, along with cost measures, which are general enough to include those structures that have already been developed and which are hopefully at the same time tractable in the sense that, given a set of task specifications, a data structure which performs the task can be extracted which falls within the confines of a given model and which is optimal or near optimal in terms of the cost measure accompanying the model. Methods from combinatorial analysis, theory of automata, and computational complexity will be brought to bear in the pursuit of this effort.

University of California (La Jolla); T. C. Hu; Theory and Computation of Discrete Optimization; (DCR 7506270); \$67,700; 24 mos.

The research is centered on "algorithms" in the broadest sense of the word. On the theoretical aspect, the following will be continued:

1. Invention of new algorithms;
2. Analysis of new and existing algorithms;
3. Implementation of algorithms by various data structures.

On the practical side, studies will be made on:

1. The effects of hardware design on the design of algorithms (how to use parallel computation, etc.);
2. The effect of compilers on algorithms. Some programs are easier to compile than others just like structured programs are more easily understood than non-structured programs.

University of California (La Jolla); Stanley G. Williamson and Edward A. Bender; Research in Combinatorial Algorithms and Asymptotics; (MCS 7402719A02); \$3,400; 24 mos. (Joint support with Mathematical Sciences - total grant, \$6,800; 24 mos.)

The research program centers around combinatorial algorithms, especially as they relate to computer science and discrete computation. A direct study of constructive recursions as sources of ranking or hashing algorithms for combinatorial algorithms will be undertaken. Further studies will be made of basic isomorph rejection algorithms and, where possible, associated ranking algorithms. Techniques relating to the evaluation of algorithms from a probabilistic point of view will be investigated in the general framework of asymptotic combinatorics. Of particular interest in this regard will be probabilistic and asymptotic techniques for the study of symmetry in algorithms.

University of Illinois (Urbana); Franco P. Preparata and David E. Muller; Complexity of Computer Computations; (MCS 7617321); \$90,700; 24 mos. (TQ)

This project will be concerned with concrete computational complexity — a field concerned with the time, memory, and equipment requirements of procedures and devices for performing specified calculations. Work will center around the three areas of computational geometry, parallel evaluation of expressions, and graph and network problems.

In the areas of computational geometry, nearest neighbor problems, convex-hull and convex-inclusion, and retrieval problems of points in n -space will be studied.

In the area of parallel evaluation, problems concerned with lower time bounds and numerical stability will be investigated.

In the area of graph and network problems, the efficiencies of known algorithms for various types of problems will be compared and new algorithms developed.

Johns Hopkins University; William H. Cunningham; Combinatorial Algorithms; (MCS 7608803); \$13,800; 24 mos.

This research is concerned with the existence of efficient algorithms for a variety of combinatorial problems, related theoretical questions, and the analysis of some known algorithms. A major area of research is that of combinatorial decomposition, where questions of unique decomposition and efficient decomposition algorithms will be considered. This subject has connections with the other areas of investigation, and to some extent unifies the effort. Research on network optimization will include network simple algorithms and matching algorithms.

Another subject of interest is that of matroids. Specific topics to be studied are algorithms for optimum bases and minimum spanning trees, algorithms for recognizing graphic matroids, and matroid sums. Finally, the applications of polyhedral theory to combinatorial algorithms will be investigated, including Chvatal's hierarchy and the determination of polyhedra relevant to given combinatorial problems from those related problems.

University of Illinois (Urbana); C. L. Liu and E. M. Reingold; Combinatorial Algorithms; (MCS 7303408A01); \$100,000; 24 mos.

The goal of this research project is to further the understanding of various combinatorial algorithms. Emphasis will be on a broad prospective of the common properties and features of classes of algorithms. It is hoped that unifying results such as techniques for analyzing and designing algorithms, general concepts concerning optimal algorithms, and performance of approximate algorithms will emerge through a concerted effort of studying several programs in each area. Some specific topics to be investigated are balance trees, approximate algorithms for discrete optimization problems, and job scheduling for multiprocessor computing systems.

Massachusetts Institute of Technology; Albert R. Meyer, and Michael Fischer; Algorithmic Complexity and Theory of Computation; (MCS 7412997A04); \$170,000; 12 mos.

The goal of this study is to develop a mathematical theory explaining why some computations are difficult to perform and others can be performed efficiently. Upper and lower bounds on the inherent computational complexity of fundamental data processing and mathematical computations such as sorting, graph manipulation, arithmetic on integers and matrices, and theorem proving in formal logic will be studied using a variety of mathematical methods.

University of Minnesota (Minneapolis); Oscar H. Ibarra; Complexity of Computations; (DCR 7517096); \$19,600; 24 mos.

This research has two objectives. The first is to develop techniques to efficiently (in terms of time and space) simulate nondeterministic computations by deterministic computations. The second objective is to find good heuristics for obtaining approximate solutions to computationally difficult problems and to identify those problems that admit fast approximation algorithms.

Rice University; D. S. Hirschberg; Parallel Graph Algorithms; (MCS 7607683); \$22,000; 24 mos.

This research project involves investigation into techniques for solving various graph problems using a parallel processing computing system. Emphasis will be on the speed of these algorithms as well as the amount of hardware required for implementation.

Stanford University; Donald E. Knuth; Some New Applications of Computers to Classical Mathematics; (MCS 7523082); \$20,000; 12 mos.

This research will concentrate on a computer assisted development of manipulation techniques for infinite series, products and continued fractions. Results thus far have already unified and extended the theory of generalized hypergeometric series, with many new summation identities. In the absence of free parameters, analogous manipulations lead to a mechanism for performing errorless, nonterminating arithmetic on these series, continued fractions, etc.

Stanford University; Robert E. Tarjan; Efficient Graph Algorithms and Their Applications; (MCS 7522870); \$29,700; 12 mos.

The objectives of this research are:

1. To develop and classify general methods for solving graph problems;
2. To apply the general methods to the solution of specific practical graph problems;
3. To analyze graph algorithms for theoretical and practical efficiency; and
4. To probe the optimality of graph algorithms and to develop lower bounds on the difficulty of graph problems.

Theory of Computation

University of California (Berkeley); M. Blum; Research in Complexity Theory and Inference; (MCS 7521760); \$39,700, 12 mos.

This research will try to show that all sufficiently slow deterministic Turing machines can be sped up a nontrivial amount by nondeterministic Turing machines, proving the existence of relatively short proofs for describing the consequences of long deterministic computations. Even for such functions as $f(x) = x^{\text{th}}$ digit of π there is no obvious proof of $f(x) = y$ that is shorter than the number of steps required to compute $f(x)$. It is felt, nevertheless, that relatively short proofs for such computations do in general exist.

The intent with inductive inference is to study the process whereby general laws are constructed from specific facts. This study borders on the study of learning and intelligence, and should provide an understanding of at least some part of this phenomenon. For a start, this work will attempt to bound the time required to compute functions. To this end, complexity theory serves as a model and provides the tools in this study of inference.

University of California (Berkeley); M. Blum; Research in Complexity Theory and Inference; (MCS 7521760A01); \$47,600; 12 mos. (TQ)

This will provide a second year of support. Scientific summary remains the same as that described above.

University of California (Berkeley); John L. Rhodes; Applied and Pure Algebra; (MCS 7601694); \$4,500; 12 mos. (Joint support with Mathematical Sciences - total grant, \$9,100; 12 mos.)

This is a continuation of work done previously under GP 20837. John Rhodes will continue his work on pure and applied algebra, further developing the existing mathematical theory of finite semigroups and finite state machines (automata) with an emphasis on the theory of complexity. Applications to the complexity of games, e.g., Chess, Go, Hex, complexity of codes, graphs, etc., will be sought.

Clarkson College of Technology; Susan C. Meyer; Analysis and Implementation of Data Driven Parallel Processes; (MCS 7607681); \$14,000; 24 mos.

This study is concerned with a group of problems related to the analysis and implementation of parallel processing systems which are data driven. Fundamental problems to be investigated concern determining conditions under which certain data flow systems can be implemented using bounded storage and examining proper allocation of operators in these systems to special purpose functional units. When data flow processes are implemented on processors having conventional architecture, the additional problems of determining legal processor initiation times and analyzing the performance of the implemented system arise. Since most data flow computations can be viewed as being comprised largely of segments, each of which may be represented by a computation graph, these problems will be investigated in the context of this model. A second group of problems to be investigated involves determining ways in which the analysis of more general data flow systems can be facilitated.

Columbia University; Samuel Eilenberg; Theoretical Computer Science; \$58,000; 24 mos. (Joint support with Mathematical Sciences - total grant, \$73,000; 24 mos.) (TQ)

This project is part of a larger project aiming at a systematization and better understanding of the theory of automata, languages and machines. The particular phase to be studied concerns that vast area of languages ranging from languages recognized by finite state machines (i.e. rational sets) to the languages recognized by Turing machines (i.e. recursively enumerable sets). Part of the research will be concentrated on algebraic sets (i.e., context-free languages) and theory of cones (i.e., abstract family of languages). Languages defined by general grammars or Turing machines will also be investigated, with special emphasis on questions of time and space complexities.

Cornell University; Juris Hartmanis; Computational Complexity; (MCS 7509433A01); \$46,100; 12 mos.

In the last few years research on lower level computational complexity has yielded a rich set of interesting results which have revealed deep and unexpected connections between various problems and thus brought new unity to this area of computer science research. This work has also yielded new techniques and insights which are likely to have further applications, and it has identified some very central problems in the quantitative theory of computing. This research program will attack some of the central problems which have emerged from previous research, which will build on this research to gain further insights into the nature of quantitative computing and which will also try to draw some general conclusions about the nature of theoretical computer science from the previous and current research in this area.

University of Florida; A. R. Bednarek and S. M. Ulam; The Role of Relational Composition in Effecting Simultaneous or Parallel Mathematical Operations on Electronic Devices; (MCS 7521130); \$53,800; 36 mos.

This proposal concerns itself with a two-track theoretical investigation, namely: (1) studies of the role of composition, particularly as far as the simultaneous or parallel realization of it is concerned, in mathematical schemata. Here the concern is to encompass the standard operations of algebra and analysis in terms of composing point or set-valued functions (relations); (2) assuming a mechanism for effecting composition in non-serial manner, the advantages of such in computer organization, the modelling of neurological-like phenomena such as iterative searches, memory building, "pattern recognition," processing of operations of the visual retina etc., will be studied.

Harvard University; Harry R. Lewis; Logic and Computation; (MCS 7609375); \$19,100; 24 mos.

The research falls in the area of overlap between mathematical logic and the theory of computation. Much of it is related, directly or indirectly, to investigations of special cases of the decision problem for first-order logic, that is, the problem of determining when restrictions on the syntax of certain formalized languages are so severe as to permit the truth or falsehood of statements in the language to be settled by mechanical means. Specific areas to be studied are:

1. Open logical and combinatorial decision problems;
2. The development of a complexity measure on reductions between decision problems;
3. The relation of the "spectrum" or set of cardinalities of finite models of a logical formula to logical and computational complexity;
4. The application to logic of results and methods from mechanical theorem-proving, graph theory, and formal program analysis;
5. The uses of logic in the theory of automata, formal languages, and program schemata, and
6. Development of a theory of proofs of computer programs.

University of Illinois (Urbana); R. S. Michalski; Variable-valued Logic: Development of Theory and Studies of Applications in Machine Perception; (MCS 7403514A01); \$6,200; 0 mos.

As part of the Small College Faculty Research participation activity, Professor Val Tareski will do research in variable-valued logic at the University of Illinois.

University of Iowa; Donald A. Alton; Computational Complexity: "Natural" and Subrecursive Complexity Measures; (MCS 7615648); \$46,900; 24 mos. (TQ)

This research will pursue an approach to efficiency considerations which use complicated programs as being built up from simpler ones which limit the "overhead cost" associated with the coordination of the resource requirements of the simpler programs during execution of the more complicated programs. This is in contrast with Blum's notion of a measure of computational complexity. Such an approach applies to subrecursive programming languages, as well as to universal programming languages. In addition, this approach rules out various measures of computational complexity which have pathological properties. Typical properties to be investigated are abstract subrecursive versions of operator speedup, an abstract subrecursive version of the non-existence of program optimizers and axiomatic distinction between "consumable resources," such as computer time and "reusable resources" such as memory.

Massachusetts Institute of Technology; Vaughan R. Pratt; Problems in the Mathematical Foundations of Computation; (MCS 7618461); \$76,200; 24 mos. (TQ)

Research on the complexity of concrete computational problems and on program semantics will be conducted. Some particular open questions to be considered are:

1. Can longest repeated substrings in a string be located in one pass, scanning each symbol for a bounded length of time (i.e. in real time)? This would lead to a good realtime text compression algorithm.
2. What is the constant of proportionality for the number of comparisons required to select the median?
3. Can $n!$ be computed as efficiently as n^n ? This could lead to a faster algorithm to test primality.
4. How much computation does it take to guess a given number, as a function of the allowed operations and control structures? The question of the relative power of determinism and nondeterminism is of particular interest in this problem.
5. Can bit-vector machines requiring only $O(n)$ logical gates for n -bit words be as efficient as the usual kind that require $O(n^2)$ logical gates?
6. How does the basis of allowed operations in Boolean expressions affect the size of the minimal expression for a given function?
7. What non-trivial classes of programs have recursively enumerable partial correctness theories? This could lead to more powerful systems of axiomatic semantics.
8. Are the first-order modal theories of finite assignment programs recursively enumerable? If so this would lead to sound, complete, effective first order axiomatic semantics for both partial correctness and termination.

Massachusetts Institute of Technology; Ronald L. Rivest; Concrete Computational Complexity; (MCS 7614294); \$74,600; 24 mos.

This research involves the study of a variety of problems in the area of decisionmaking and searching algorithms. The emphasis will be on developing new techniques for proving lower bounds on their complexities.

Some of this research represents a continuation of previous work on the Aanderaa-Rosenberg conjecture, associative search algorithms, optimized hash tables, and certain combinatorial questions. Other problems represent either a significant question studied for its own merits (such as verifying partial orders) or restricted versions of larger, more difficult problems (determining the monotone complexity of Boolean functions). In general the problems relate more or less directly to the complexity of practical, common functions.

University of Massachusetts (Amherst); Michael A. Arbib and Ernest G. Manes; Categorical Machine Theory, with Applications to Syntax-Directed Translation and Control Theory; (MCS 7203733A02); \$6,500; 12 mos.

The work of Arbib in unifying automata theory and system theory and the work of Manes on providing a categorical framework for the study of universal algebras is being used to provide a framework for the study of machines. The resulting theory will be applied to syntax-directed translation and control theory.

University of Minnesota (Minneapolis); Sartaj Sahni; Investigation of Polynomially Complete and Hard Problems; (MCS 7621024); \$45,100; 24 mos. (TQ)

This research will address itself to the following problems:

1. Are there any "natural" NP-complete problems solvable by an algorithm with polynomial expected behavior?
2. Are there subexponential worst case algorithms for natural NP-complete problems such as 0/1 Knapsack, etc.?
3. Obtain generalized and refined approximation techniques applicable to large classes of NP-complete problems.
4. What is the status of problems such as max clique, job shop scheduling to minimize finish time, flow shop scheduling to minimize finish time, etc., with respect to approximation algorithms?
5. Obtain tools to measure the expected performance of heuristics.

Intelligent Systems

University of California (Santa Cruz); David A. Huffman; Curvature and Convexity in Scene Analysis Problems; (MCS 7512814A01); \$25,000; 12 mos.

This study will investigate the interrelationships that exist among various parameters of surfaces in scenes and how they affect the information that is recorded in pictures of these surfaces. Knowledge of these interrelationships will better the ability to deduce facts about a scene from pictures of that scene.

Special attention will be focused on the effects of surface curvature and convexity (or concavity) and the mutual interactions of these parameters and those that are associated with the direction of the illumination, the orientation of the surface and its texture and light reflecting characteristics.

This is the second year of a three-year continuing grant.

University of California (Los Angeles); Judea Pearl; Investigating Computational Gains from Inexact Processing; (MCS 7518734); \$23,400; 30 mos. (Joint support with Techniques and Systems Program - total grant, \$46,700; 30 mos.)

The ultimate goal of this research is the construction of a computer-based question-answering system which is capable of making useful, though imprecise, inferences about a given data base. Such a system should be able to incorporate approximate statements in its answer vocabulary (e.g., "It probably did rain in Washington on August 1, 1974, but I am only 80% sure"), and draw generalizations on data not contained in the stored data (e.g., "It will probably rain tomorrow, but I am only 80% sure"). While the use of approximate answers to queries about unobserved facts is mandatory, its usage for answering queries about observed facts is prompted by consideration of computational economy. It is intended to cut down the amount of data admitted into memory, to economize on the amount of data in the easily accessible portion of memory and cut down the amount of search into lower levels (containing finer detail) of memory. The first step in this direction is the development of techniques for quantifying the memory versus error tradeoffs in question-answering systems.

Carnegie Mellon University; Peter B. Andrews: Proof Procedures in Type Theory; (MCS 7606087); \$45,000; 24 mos.

This research is directed toward enabling computers to prove theorems of mathematics and other disciplines formalized in type theory or in predicate calculus. An existing computer

program implementing a unification algorithm and resolution rules for type theory will be applied to examples, extended, and improved. A fundamental result about *matings* (Occurrences of potentially complementary literal-occurrences) will be analyzed further, and used as the basis for a new proof procedure for first order logic. Other relevant ideas and problems will also be explored.

Case Western Reserve University; George W. Ernst; Application of Heuristic Techniques; (MCS 7523412); \$16,000; 24 mos. (Joint support with Software Quality Research Program and Techniques and Systems Program - total grant, \$47,800; 24 mos.)

This research is in two areas associated with heuristic methods in Computer problem-solving. The first area will continue to develop a system which verifies Pascal programs (i.e., proves them to be correct). The planned system will be applied to a large number of different kinds of programs. These will fall into two categories:

1. Isolated programs that have different features;
2. A number of program modules that constitute a small portion of a real system.

New theorem-proving methods will be developed and incorporated into the planned system. A special feature of the system is that it used both resolution and nonresolution theorem-proving in an essential way. In the second area, a program will be implemented that can discover heuristics for certain problem-solving methods. For each method being considered, a formal condition has been derived which characterizes the class of problem for which the method is useful. These formal conditions specify "good" parameters to the methods.

University of Maryland (College Park); Azriel Rosenfeld; Computer Processing of Pictorial Information; (MCS 7203610A04); \$134,300; 12 mos.

This project is part of a broad research program in the computer processing of pictorial information. It is concerned with the automatic analysis of complex scenes, and with the development of formal models for scene analysis. Emphasis is placed on four areas:

1. Development of techniques for segmenting a scene into regions that are significant to the description of the scene;
2. Analysis of the geometrical properties of regions, and application of the results to improving scene segmentations;
3. Modelling of human perceptual processes as they relate to scene segmentation and description (texture discrimination, shape constancy, etc.), and
4. Studying automata that accept graph-structured, rather than string-like, "tapes", and of formal grammars that generate graph-structured "sentences". Such structures provide a formal model for scene description.

University of Massachusetts (Amherst); Edward M. Riseman; A Semantically Directed Vision Processor; (DCR 7516098); \$76,600; 24 mos.

This research involves the development of the higher level processes for manipulating the interaction of many forms of complex information in building conceptual models. The types of information that must be accessed include:

1. Visual data extracted in the cone;
2. A semantic data base of general knowledge;
3. Context settings, (winter, outdoors, rural area, etc.);
4. The partial model that has been constructed;
5. Context frames representing expected submodels or stereotypes in the world; and

6. Perspective and occlusion routines.

An executive in the model builder must allow communication among many types of modules, encompassing information in both declarative and procedural representations. It must embody an overall strategy for constructing models.

New York University; Martin Davis; Computation and Logical Proof Procedure; (MCS 7162039A06); \$5,900; 6 mos.

As part of the Small College Faculty Research participation program, Professor Rona Curkewitz will do research in automatic theorem-proving at New York University.

New York University; Martin Davis; Computation and Logical Proof Procedure; (DCR 7102039A05); \$67,900; 12 mos.

The main goal is to provide a theoretical basis for improved search procedures in linked conjunct algorithms. The present theoretical work on restrictions on necessary links will be continued, and improvements thus obtained will be incorporated into the existing program library.

Programming efforts in connection with improved linked conjunct theorem provers will be continued. New formats will be incorporated into the present resolution and model-elimination programs in order to maximize compatibility. All the existing project programs will be incorporated into a single system controlled by a special-purpose Herbrand theorem-proving language.

Methods for mechanical theorem-proving in number theory (with special reference to solvability of specific Diophantine equations) will be investigated.

Purdue University; Keinosuke Fukunaga; Feature Extraction and the Application of the Branch and Bound Method to Statistical Pattern Recognition; (MCS 7602050); \$45,200; 24 mos.

In this research of statistical pattern recognition, special emphases are placed on feature extraction and the application of the branch and bound method.

Systematic procedures for extracting the effective features for classification have not been adequately explored despite the importance. A formulation of nonlinear mapping is to be investigated. This might provide a bridge between feature extraction and the approximations of density functions. Another approach is to view feature extraction as a clustering problem. Also, the evaluation procedure of selected features will be studied.

The second research topic is to view pattern recognition as a data management technique concerned with storing, retrieving, labeling and grouping a large amount of data. In order to meet this goal, every aspect of pattern recognition has to be reformulated as a combinatorial optimization problem. The branch and bound method may provide a very efficient search procedure of the optimum solutions.

Stanford Research Institute; Harry G. Barrow; Equilibrium Processes in Automated Scene Analysis; (ENG 7601272); \$40,000; 12 mos. (Joint support with Engineering Sciences - total grant, \$80,000; 12 mos.)

In this research, the concept of an equilibrium process is explored to show how equilibrium processes occur naturally in several implementations of scene analysis systems. The equilibrium process combines the segmentation and interpretation functions and is, therefore, applicable to a broader class of problems. In addition, the research program will demonstrate the general

importance and advantages of equilibrium processes, develop facilities for their use, and implement a basic system for segmentation of real pictures that may be readily extended into special-purpose systems for particular applications.

Temple University; Ranan Banerji; Learning Recursive Descriptions by a Positive Focusing Strategy; (MCS 7602001) \$19,000; 12 mos.

This research seeks to increase the understanding of how to design a computer program which can learn from experience. In the present phase of the research, the experience will take the form of a human teacher who exhibits to the program a typical example of a class of objects he has in mind but cannot quite describe (or does not want to describe, as will happen during the initial test of the program). The program analyzes the example to ask relevant questions about the class concerned which the teacher answers. (It is expected of the teacher that even if he cannot describe the class he has in mind, he can recognize an erroneous description when he sees one.) This enables the machine to home in on the correct definition of the class under consideration. In later phases of this research, "experience" would take the form of inputs from a problem-solving program, which exhibits to the learning program those problem situations from which solution was particularly difficult or easy. The learning program then forms abstract descriptions of the kinds of situations which the problem-solving program should avoid or seek out in the future.

University of Texas (Austin); W. W. Bledsoe; Research in Automatic Theorem-Proving; (DCR 7412866A01); \$37,800; 12 mos.

This research is a continuation of present research in automatic theorem-proving. Earlier work has included heuristically directed programs, results in resolution theory, semantically oriented programs and man/machine provers applied to topology. This investigation will continue this work, including program verification and applications of automatic theorem-proving to nonstandard analysis.

University of Wisconsin (Madison); Leonard Uhr; Computer-Programmed Models of Wholistic Integrated Cognitive Systems; (MCS 7607333); \$34,000; 24 mos. (Joint support with Techniques and Systems Program - total grant, \$67,500; 24 mos.)

This project involves research for developing a computer-programmed model of the mind/brain where the various cognitive processes are integrated into a single wholistic system. The long term goal is to achieve a system that can learn to perform the variety of cognitive tasks handled by an ordinary human being. This means that the single system must be able to effect a wide range of processes, to recognize patterns, describe scenes, form concepts, solve simple problems, understand language, access and converse about remembered information, act upon and manipulate its environment, and learn.

University of Virginia; John L. Pfaltz; Surface Networks for the Study of Graphical Data; (MCS 7413353A01); \$14,000; 12 mos. (Joint support with Special Projects Program - total grant, \$30,000; 12 mos.)

Surface networks are directed graphs analogous to the network of ridges and courses connecting the peaks, passes (saddles), and pits of geographic surface. This project will explore these networks as a tool for investigating and describing not only geographic surfaces, but general functional surfaces occurring in a wide range of disciplines using computer graphics.

Numerical Analysis and Computational Mathematics

University of California (Los Angeles); Arthur M. Geoffrion; Optimization of Large-Scale Systems; (MCS 7523350); \$11,000; 12 mos. (Joint support with Physics, Engineering Sciences and Mathematical Sciences - total grant, \$51,600; 12 mos.)

This is a continuation of work done previously under GP 26294.

Work will continue on optimization of large-scale systems. Three major areas will be considered. The first is the optimization of projected or dualized convex mathematical programs for the design and coordination procedures for decentralized systems. The topics in this area include local improvement and global approximation methods, robustness and rate of convergence. The second area is large-scale integer programming with emphasis on implicit enumeration and decomposition methods. The third area concerns the application of recent advances in the preceding areas to the allocation of resources in and control of large-scale networks.

Carnegie Mellon University; J. F. Traub; Parallel Algorithms and Computational Complexity; (MCS 7522255); \$39,800; 12 mos.

Research in many areas of algorithms and complexity continues. Areas include parallel, asynchronous, algebraic, iterative, and combinatorial. The emphasis continues on algorithms and complexity results relevant to real computation. It is anticipated that problems of interest will be heavily influenced by the rapidly changing technology, particularly in hardware and architecture.

University of Colorado; Linda Kaufman; Research in Using Matrix Decomposition in Function Minimization and Eigenvalue Problems; (MCS 7523333); \$14,800; 24 mos. (Joint support with Software Quality Research - total grant, \$29,600; 24 mos.)

In recent years techniques have been developed for the creation and the updating of various matrix decompositions such as the singular value decomposition, the orthogonal decomposition and the decomposition of symmetric matrix. The purpose of this research is to apply these techniques to minimization problems and certain eigenvalue problems. Emphasis will be on algorithm development and implementation.

Colorado State University; Stephen F. McCormick; A Numerical Investigation of Iterative Method for Solving Linear and Nonlinear Equations; (MCS 7609215); \$34,200; 24 mos.

This investigation is involved with the development and analysis of several iterative methods that apply to many diverse problems including linear and nonlinear algebraic equations, constrained optimization, boundary value problems, partial differential equations, and linear and rational approximation. Several important issues have been raised in connection with these algorithms, including new ideas for some promising methods of the type considered. Both theoretical and numerical efforts will continue to test known methods in their applications to new problems and pursue the ideas for the more efficient techniques being developed.

Cornell University; Charles Van Loan; Explicit Computation of the Matrix Exponential; (MCS 7608686); \$20,600; 24 mos.

The principal goal of this research is to identify through experimentation and analysis the capabilities of the many algorithms which exist for explicit computation of the matrix exponential. It is planned to develop improved routines and to learn precisely when exponential computation is an economic proposal in the course of solving initial value problems. Also studied will be various problems in control theory which involve the matrix exponential.

Illinois Institute of Technology; Melanie L. Lenard; Nonlinear Optimization Without Evaluating Derivatives; (MCS 7610821); \$29,000; 18 mos.

Numerical methods for optimizing a nonlinear differentiable function of many variables usually require the evaluation of (at least) the first partial derivatives, or gradient, of the objective function. However, in many practical situations, derivative information can be difficult, if not impossible, to obtain directly. Existing non-derivative optimization methods rely on accurate finite-difference approximations for first derivatives or on accurate solutions to a sequence of one-dimensional optimization problems. It is believed that the numerical difficulties inherent in either procedure can be avoided or substantially reduced by a new approach to non-derivative optimization, which this project will study. The new approach uses sets of conjugate search directions combined with an accelerating, or quasi-Newton, step. Since the one-dimensional optimization problems need not be solved accurately and since the accelerating step requires only η extra function evaluations (for a function of η variables), this new method seems to make effective use of function evaluations. This project is to study the theoretical properties of the new method to obtain convergence and rate of convergence results and to implement the new method with a computer program and compare its performance with that of existing methods on standard test problems.

University of Illinois (Urbana); David J. Kuck and Ahmed Sameh; High Quality Software for Numerical Computation; (MCS 7521758); \$23,300; 12 mos. (Joint support with Software Quality Research - total grant, \$46,600; 24 mos.)

This research is concerned with the problem of how to create high-quality software for future multioperation computers. The objective is to be able to compile a numerically stable algorithm for a multioperation machine from a numerically stable sequential algorithm, when possible, through the mechanism of properly parsing the algorithm. The class of algorithms to be studied is limited to those of linear algebra, but the research applies to the larger problem of high-quality compilers and languages for multioperation computers.

University of Iowa; Kendall Atkinson; Numerical Solution of Integral Equations; (MCS 7606094); \$17,900; 24 mos. (Joint support with Software Quality Research Program - total grant, \$35,800; 24 mos.)

This project is concerned with the numerical solution of Fredholm linear integral equations of the second kind. The integral equation problems to be considered are as follows: (1) extension of previous work to the case in which the solution function has singularities in some low-order derivative; (2) systems of integral equations; (3) integral equations with a singular kernel function; (4) multidimensional integral equations; and (5) the eigenvalue problem for integral operators, especially the case of a real, symmetric kernel function which is several times continuously differentiable. The main numerical techniques to be used are variations of the Nystrom method, with both direct and iterative methods of solution for the resulting linear system.

Kansas State University; Richard F. Sincovec; Numerical Methods for Partial Differential Equations; (MCS 7607684); \$41,100; 24 mos.

The numerical solution of partial differential equations that describe physical processes is a major use of scientific computing resources. General purpose computer software for the numerical solution of these equations is almost strictly limited to problems involving only one-space and one-time variable. Most of these programs are based on the numerical method of lines, an approach which has been found to be very effective in solving difficult engineering problems and quite amenable to the development of generalized software.

The purpose of this research is to investigate the numerical method of lines approach in more detail including extensions to higher dimensions. The results of this research should lead to better software for partial differential equations in one-space variable and determine the feasibility of developing generalized computer software for large classes of problems in two spatial variables via the method of lines approach.

University of Kansas; Lois Mansfield; Finite Element Methods for the Solution of the Navier-Stokes Equations; (MCS 7606293); \$19,900; 24 mos.

This project will develop and obtain error bounds for finite elements methods for the solution of stationary Navier-Stokes equations using piecewise polynomial basis functions which satisfy a weak form of the continuity equation. This project will also implement the methods obtained and compare their efficiency and accuracy with other finite element methods for the solution of stationary Stokes and stationary Navier-Stokes equations. In addition, this project will develop finite methods for the solution of nonstationary Navier-Stokes equations.

University of Maryland (College Park); W. C. Rheinboldt and J. S. Vandergraft; The Numerical Solution of Nonlinear Systems of Equations; (MCS 7203721A04); \$51,500; 12 mos.

This research program on the numerical solution of nonlinear systems of equations has the following three broad aims:

1. Study of the form and properties of classes of nonlinear systems of equations and of iterative methods for their solution, with particular emphasis on large, sparse systems of the type arising, for instance, in connection with the finite element solution of boundary value problems;
2. Investigation of the underlying combinatorial structure of classes of large sparse systems of nonlinear equations and of suitable data structures for their representation in a computer;
3. The development of and numerical experimentation with overall algorithms for the classes of systems under study, which interrelate the combinatorial aspects, the data structures used and the specific numerical methods.

University of Maryland (College Park); W. C. Rheinboldt and J. S. Vandergraft; The Numerical Solution of Nonlinear Systems of Equations; (MCS 7203721A05); \$5,500; 12 mos.

Under the Research Opportunities for Small College Faculty Activity, Dr. John Fitzgerald of Goucher College, Baltimore, Maryland will be conducting research on the numerical solution of nonlinear equations.

University of Michigan (Ann Arbor); Dianne P. O'Leary; Conjugate Gradient Algorithms for Nonlinear Elliptic Equations; (MCS 7606595); \$6,600; 12 mos.

The purpose of this research is to develop the use of the conjugate gradient algorithm with matrix-splitting techniques to solve nonlinear problems, in particular, those arising from finite difference discretizations of elliptic partial differential equations. Algorithms of this type have already been shown to be efficient on linear partial differential equations, and preliminary investigations have demonstrated their promise in the nonlinear case. The research will involve theoretical development and computational experimentation to determine efficient and reliable nonlinear conjugate gradient formulations and their conditions for convergence, as well as to develop algorithms which could be applied to large systems of nonlinear equations with inequality constraints.

National Bureau of Economic Research, Inc.; Jeremy F. Shapiro; Dual Methods for Mixed Integer Programming: Sensitivity Analysis, Multicriterion Optimization and Decomposition; (MCS 7520988); \$52,300; 24 mos. (Joint support with Special Projects - total grant, \$77,300; 24 mos.)

A complete duality theory for mixed integer programming has recently been developed. The theory involves the construction of a finite sequence of increasingly strong dual problems; the last dual problem in the sequence provides an optimal solution to the mixed integer programming problem. The duals are nondifferentiable concave maximization problems. The research will focus on the numerical and computational aspects of constructing and solving the dual problems. Their use in conjunction with branch and bound will also be studied further. Extensions of the dual methods will be condensed to sensitivity analysis, multicriterion optimization and decomposition of mixed integer programming problems.

North Carolina State University; John A. Roulier and David F. McAllister; Constrained Interpolation with Applications; (MCS 7604033); \$30,800; 24 mos.

The investigators will examine restricted interpolation (Lagrange, Hermite, Hermite-Birkhoff) where the interpolant must satisfy side constraints such as monotonicity, convexity, comonotonicity, etc. They will investigate the existence of such interpolants and develop algorithms to compute them.

They also intend to evaluate their methods in the numerical solution of ordinary and partial differential equations where some of the coefficients or boundary conditions are functions whose values can be measured or calculated and where some information on the shape of the function is known.

Purdue University; Walter Gautschi; Numerical Analysis; (MCS 7600842); \$13,400; 12 mos.

This project involves investigations into various problems associated with quadrature formulas of the Chebyshev type. Symbolic manipulation techniques will be used to answer several questions concerning minimum norm quadrature rules. The degree of ill-conditioning for special matrices, especially Vandermonde matrices, will be studied using optimization methods.

Stanford University; George B. Dantzig, Richard W. Cottle and Robert Wilson; Computer Optimization of Complex Systems; (MCS 7504544A01); \$25,000; 6 mos. (TQ)

The goal of this research is to systematically develop, test and compare algorithms for

optimizing large-scale systems which are modeled on computers. Programs will be examined for such factors as computational accuracy and the efficiency of use of computer resources. Representative examples for the research would be drawn from models of energy production and distribution, ecological systems and food production.

This is a renewal of Grant No. DCR 7504544.

Stanford University; Gene H. Golub and Joseph Oliger; Computing Methods in Numerical Analysis; (DCR 7513497); \$49,600; 12 mos.

The purpose of this project is to develop, study and analyze algorithms and methods for solving numerical linear algebra problems and initial value problems for partial differential equations. Principal activities are centered around improving algorithms for computing eigenvalues and eigenvectors of the generalized matrix problem $Ax = \lambda Bx$, applying techniques of mathematical programming for solving physical problems, e.g., free boundary problems and studying techniques to automatically and adaptively insert mesh refinement.

Stanford University; Gene H. Golub; Computing Methods in Numerical Analysis; (MCS 7513497A01); \$37,200; 12 mos. (TQ)

This is a continuation of research previously supported. Scientific summary remains the same as that described above.

University of Texas (Austin); Dale G. Bettis and David G. Hull; High Order Runge-Kutta Methods; (DCR 7517309); \$16,900; 12 mos. (Joint Support with Software Quality Research Program - total grant, \$33,800; 12 mos.)

The purpose of this study is to develop efficient high-order explicit Runge-Kutta methods for solving the initial value problem for systems of ordinary differential equations. An efficient method yields a solution of a specified accuracy with a minimum cost. Cost is measured as the total computing time and/or the total number of function evaluations. Recent test results comparing multi-step, extrapolation, and Runge-Kutta methods show that the Runge-Kutta methods are very competitive with the other methods, particularly when the function evaluations are not expensive.

The methods to be developed will have an accurate estimate of the local truncation error term, thereby allowing the implementation of a variable-step (and, possibly, a variable-order) strategy. The coefficients of the Runge-Kutta method will be selected so that the local truncation error is minimized and that the stability region is maximized. Also, the coefficients will be chosen so that a quadrature problem can be solved by the method and that, in this case, the local truncation error estimate is reliable.

The new Runge-Kutta methods are to be developed for systems of first-order differential equations. The feasibility of extending the techniques to the generation of methods or systems of second-order (and higher) ordinary differential equations will be considered.

University of Texas (Austin); Dale G. Bettis and J. Tinsley Oden; Runge-Kutta and Runge-Kutta-Nystrom Formulas and Software; (MCS 7610022); \$41,200; 24 mos. (Joint support with Software Engineering - total grant, \$61,800) (TQ)

Embedded pairs of explicit Runge-Kutta and Runge-Kutta-Nystrom methods will be developed for systems of first- and of second-order ordinary differential equations. These methods have an accurate estimate of the local truncation error, allowing the implementation of a variable-step and a variable-order strategy. Coefficients are selected so that the local truncation error is minimized and that the stability region is maximized. Also, coefficients for

lower order methods of the pair are obtained. Methods will be developed for the special case in which the first m total derivatives are known.

Augmentative Theoretical Studies

University of California (Berkeley); Lotfi A. Zadeh; Computation with Linguistic Variables; (MCS 7606693); \$32,900; 24 mos.

The theory of fuzzy sets provides a basis for the development of computational techniques for the manipulation of quantities which are expressed in linguistic rather than numerical terms. The development of such techniques and their application to problems in inference from fuzzy data, decision-making under uncertainty, and the representation of knowledge are the principal aims of this research.

University of Michigan (Ann Arbor); Arthur W. Burks; Formal Modeling and Simulation of Natural Systems; (DCR 7101997A05); \$163,700; 6 mos.

The research program being carried out has three interrelated parts:

1. The study of formal, dynamic models of complex natural and artificial systems, and in particular the formal study of adaptation;
2. Computer experiments, including the simulation of natural (especially biological) systems exhibiting adaptation, computer explorations of various algorithms for learning and adapting, and the use of the computer as a heuristic aid to formal, mathematical research;
3. The use and further refinement of a computing system permitting online, interactive, computer-aided research.

Northwestern University; Jon T. Butler; Synthesis and Analysis Techniques for Finite Cellular Arrays; (MCS 7600326); \$12,000; 24 mos.

This research focuses on the development of a design algorithm for cellular systems. In particular, given a global transition function, which describes the overall behavior of the array, one is interested in determining the sequence of local transition functions which produce the desired behavior. The global transition function is specified in whole or in part by a set of pattern pairs where the desired output pattern is shown for the corresponding input pattern. If this function is realizable, it implies a "composite" local function that has a special decomposition, from which the separate local transition functions can be extracted.

Pennsylvania State University; Jonathan Goldstine; Grammatical Families and Parsing; (MCS 7610076); \$48,000; 24 mos.

A grammar form consists of all "interpretations" of a master grammar, that is, all grammars whose productions sufficiently resemble those of the master grammar. However, the families of grammars that are important in the study of parsing and compiler design are not defined by the form of their productions. Therefore, a different notion of interpretation is needed in order to obtain a mechanism for specifying families of the type important in programming. Different kinds of interpretations will be investigated, and within this general framework, some questions relating to parsing methods and parsing complexity will be studied. One goal will be to characterize classes of grammars, each parsable by the same techniques and in the same amount of time.

University of Pittsburgh; Robert P. Daley; Minimal-Program Complexity; (MCS 7600102); \$26,200; 24 mos.

This computer science research project is in the area of computational complexity. It deals with an inference problem which seems related to the scientific investigation of phenomena. There are also some questions relating to the characterization of sequences having low complexity. Additionally some new research questions in the area of minimal-problem complexity will be considered concerning the notions of speedability, effective speedability and levelability from abstract complexity theory. It also involves the study of the question of whether there exists a tape hierarchy for multitape Turing machines operating in linear time.

Purdue University; Paul R. Young and Michael Machtey; Mathematical Theory of Computation; (MCS 7609212); \$93,600; 24 mos.

Computer Science is the study of algorithms, their behavior and efficient implementation. This research project will continue basic studies on what algorithms are, how they behave, and how one can measure their use of resources. This will be accomplished by continuing or beginning work in the following areas:

1. Recursion theoretic consequences of demanding proofs of correctness for programs.
2. Theory of translators and acceptable programming systems. Here a basic problem is to characterize enough of the *structure* of the systems to be able to prove, for example, that translators must simulate, i.e., must "preserve the underlying structure of the algorithms being translated."
3. Infeasibility of algorithms for programming structures and schemes.
4. Consequences of P vs NP and the polynomial degrees. It is hoped to continue investigation of the polynomial degrees and to locate some specific, *naturally* occurring problems *above* the complete sets in the P-Hierarchy (assuming $P \neq NP$).

University of Southern California; Seymour Ginsburg; The Theory of Grammars; (MCS 7303380A01); \$48,100; 24 mos.

The aim of this study is to examine the grammar form model as well as to find the other grammar type models which will lead to a better understanding of families of grammars and their role in computer activity. As such, three general goals may be singled out:

1. Investigate properties of grammars, such as "structural closeness," "is an interpretation of," etc., which can be formulated within the present model;
2. Find relevancies and applications of the present model to computer science;
3. Seek other models of families of grammars which can account for situations not encompassed by the present model.

Texas A & M University; Itshak Borosh; Applications of Modular Arithmetic; (MCS 7606092); \$18,700; 24 mos.

The advantages of modular arithmetic are that the size of the numbers involved is kept under control, the method is free of round-off errors, and is suitable for parallel computation. However, it is not universally applicable. The goal of this project is to broaden the range of applications of modular arithmetic, in particular its application to Hermite and Smith normal form of matrices with integer or polynomial entries. In addition the feasibility of algorithms obtained by combining modular arithmetic with other techniques such as Interval Arithmetic or p-adic methods will be investigated.

University of Texas (Austin); James L. Peterson; Petri Nets and Languages: (MCS 7516425); \$18,100; 24 mos.

Petri nets can be used for modelling the behavior of a system of concurrently executing processes. Current research on Petri nets has focused on properties of the net such as liveness and safeness. By defining the set of possible transition firings for a Petri net as the language of the Petri net, we can borrow concepts from formal language theory and automata theory and apply these concepts to the analysis of Petri nets. Several different definitions for the language associated with a Petri net have been offered, and the differences between these languages and their properties will be considered. Finite state machines and marked graphs are subclasses of Petri nets and their languages will also be investigated.

Vanderbilt University; Robert A. Wagner; Research into Formal Language Error Correction; (MCS 7604539); 24 mos.

Compilers which incorporate extremely sophisticated error recovery procedures recently have achieved substantial acceptance. These compilers make attempts to "correct" erroneous source programs, by changing those programs into acceptable programs which differ as little as possible from the originally submitted source. The purpose of this project is to develop a "theory" of formal language correction, analogous to the existing theory of formal language recognition. If successful, this theory should lead to algorithms which produce error-correcting compilers automatically, from the grammar describing their source language. The theory might also be applicable to the measurement of a language's "correctability".

University of Wisconsin (Madison); Lawrence H. Landweber; Properties of Petri Nets and Related Models; (MCS 7617323); \$33,400; 24 mos. (TQ)

Petri nets have been extensively studied as models for asynchronous processes. Applications have involved such diverse areas as fault tolerance, synchronization of parallel processes, traffic flow, resource flow in an urban model, programming language semantics, computer system modelling and network modelling.

The research involves the investigation of the mathematical properties of Petri nets and related models. Of particular interest is the existence of algorithms for various problems and the complexity of those problems which have algorithmic solutions. A long term goal is a solution to the reachability problem. An algorithmic solution to this problem would have many significant applications. For example, one could decide whether a particular resource pattern could be achieved in an urban model or whether a particular process could eventually be activated in a computing system. To solve this problem, we must first acquire a better understanding of the combinatorial properties of the model. In particular, the role of various characteristics such as persistence and semilinearity will be explored. Subclasses of Petri nets will also be characterized. Such studies are necessary if Petri nets are to achieve their full potential as models as asynchronous information processing.

Yale University; Ronald V. Book; Computational Complexity and Formal Languages; (MCS 7605744); \$51,200; 24 mos.

Research in automata-based computational complexity and in formal language theory will be conducted. Emphasis will be given to the central questions of automata-based computational complexity, in particular the cost of deterministic simulation of nondeterministic processes, time space tradeoffs, and the classification of subelementary functions and predicates by the complexity of their syntactic definitions. The methodology is strongly influenced by the results and techniques of formal language theory and recursive function theory. Results in the theory of complexity will be applied to problems of formal language theory and to problems of subelementary functions and predicates.

Yale University; Martin H. Schultz and David P. Dobkin; Concrete Computational Complexity; (MCS 7611460); \$31,300; 12 mos. (TQ)

Concrete complexity theory involves the study of optimal algorithms for concrete, practical problems of computation. The goals of these studies are the synthesis of efficient algorithms for the solution of such problems as well as lower limits on the efficiency of any algorithm to solve the problems. The investigators will study the complexity of computations of the analytic and arithmetic types. Within analytic complexity the investigators will study computations for approximating general functions and for solving nonlinear and sparse linear systems of equations. The evaluation of bilinear operations will be the focus of this research in arithmetic complexity.

Studies and Colloquia

Carnegie-Mellon University; J. F. Traub; Symposium on Algorithms and Complexity: New Directions and Recent Results, April 7-9, 1976, Pittsburgh, Pennsylvania; (MCS 7609725); \$5,600; 8 mos.

The emphasis of the Symposium is on algorithms and complexity results relevant to actual computation. There are survey papers summarizing the state of the art and research papers announcing new results. Of interest are results in areas which have traditionally been subject to algorithmic analysis, as well as new areas which may now be amenable to such analysis.

Texas A & M University; Richard E. Fairley; Regional Conference on Computational Complexity of Feasible Computations, Texas A & M University, College Station, Texas, January 3-8, 1977; (MCS 7609287); \$12,000; 9 mos. (TQ)

This conference is one of a series of five (5) day regional conferences being funded by the NSF. Supporting services for the handling of the proposals for these conferences and for the conduct of these conferences is provided by the Conference Board of the Mathematical Sciences (CBMS) through the medium of a contract with the Foundation.

The objective of these conferences is to stimulate and broaden research activity across the spectrum of the mathematical and computer sciences, particularly in areas where such activity is lagging. Each conference has a principal lecturer (generally not from the host institution) and about twenty five (25) other invited participants, drawn from the broad geographic region around the host institution. There will be at least two lectures by the principal lecturer each day, with the remainder of the day available for study, informal seminars, and exchange of ideas. These lectures will be published as a research monograph by either the American Mathematical Society or the Society for Industrial and Applied Mathematics.

Dr. Juris Hartmanis will give a series of lectures on "Recent Developments in the Computational Complexity of Feasible Computations". In the last few years research in computational complexity has yielded a rich set of interesting results which have revealed deep and unexpected connections between various quantitative problems about computing and brought new unity to this area of computer science. This work has also yielded new techniques and insights which are likely to have further application in many areas of computer science.

SOFTWARE AND PROGRAMMING SYSTEMS

Programming Languages and Compilers

University of California (Los Angeles); M. A. Melkanoff; MADCAP Language and Data Bases: (MCS 7423536A01); \$3,000; 0 mos. (TQ)

This project is aimed at making MADCAP VI (a programming language originating at the Los Alamos Scientific Laboratory) available to a large and varied community of users. The present award is to complete the publication and distribution of system documentation.

Cornell University; Robert L. Constable and James E. Donahue; Investigations in Language Design and Formal Semantics; (MCS 7614293); \$114,000; 24 mos. (TQ)

This project includes work in three areas:

1. Language design: Coordinating with the PL/C group to design a simplified language for pedagogic purposes. Assertions are to be included and the semantics specified by an axiomatic description and a definition in the style of Scott's denotational semantics.
2. Applied semantics: Simula-like modules and facilities for parallelism will be evaluated and their semantic implications considered. Proof rules for new features will be studied and a logic defined for reasoning about LISP programs.
3. Semantic theory: Among the issues to be treated are the choice of logical primitives for reasoning about programs, systems for proving program termination and verification techniques for performance properties of parallel programs.

Indiana University (Bloomington); Daniel P. Friedman and David S. Wise; Structured Recursion: Its Properties, Translation, and Implementation; (MCS 7508145); \$54,600; 24 mos.

High level languages have historically implied inefficiencies at run-time. Restrictions will be sought on the style of such languages which would not hamper their power, but which would guarantee compilation to efficient machine code. In particular, an investigation of a characterization for "structured recursion" is sought which would allow a compiler to introduce iterative loops to replace single recursions and to minimize the use of stacks, using borrowed space if possible, for multiple recursions. The long term objective is the design of a prototype language which would present the new restrictions to the user comfortably.

Indiana University (Bloomington); Mitchell Wand and Daniel P. Friedman; Formal Semantics of Programming Languages; (DCR 7506678); \$37,000; 24 mos.

One goal of formal semantic theories of programming languages is the development of new, more systematic programming languages, but to date no major programming language has been based directly on an explicit, formal semantic theory of computation. An exceptionally simple and perspicuous semantic model of computation has been proposed which will be further developed and used to study various programming language features.

New York University; Jacob T. Schwartz; Studies of Very High-Level Programming Techniques and of the Optimization of Very High-Level Languages; (MCS 7600116); \$291,000; 12 mos.

The very high-level set-theoretically based programming techniques developed under a preceding NSF grant allow complex processes to be programmed far more easily than is possible using conventional techniques. The main obstacle to the spread of these techniques is their run-time inefficiency. This makes it clear that global optimization of high-level languages is an issue of central importance. Under this grant optimizations of this class will be investigated theoretically and pragmatically, both for their own set-theoretic language SETL and for other interesting very high-level languages such as SNOBOL.

Oklahoma State University; George E. Hedrick; A Study of Transput in Algol 68; (MCS 7606090); \$88,600; 24 mos.

Research will be carried out on the transput (input/output) facilities of the programming language Algol 68. Transput facilities of the language are rigorously defined in the Revised Report on Algol 68 by van Wijngaarden and others. The formal definition includes many more items than can be studied in this project so the scope of the study will be limited to formatted transput that can be incorporated into the presently working OSU subset prototype compiler.

The results of this research should be techniques which can be used for the incorporation of transput processing facilities into other Algol 68 compilers in particular and insights into the nature of transput processing in general.

Oregon State University; Ted G. Lewis; Development of a Systems Implementation Language for Realizing Virtual Systems; (MCS 7620710); \$61,100; 24 mos.

Microprogramming requires careful planning because it involves machine dependency, concurrency recognition and special purpose control structures. This research addresses a transportable, high-level language and its translator for the production of high quality microprograms. This is done by extending an existing systems programming language called IML. The IML is reduced to a machine-dependent form by writing semantic monos that complete the translation. The IML must be carefully designed to include features of a broad class of host machines. The IML semantic routines must be of sufficient power and versatility to generate efficient code for a variety of host machines. Transportability is accomplished through the use of a generalized IML.

Polytechnic Institute of New York (Brooklyn); Melvin Klerer and Fred Grossman; Interactive 2-Dimensional Programming and Integrated Computer Input/Output; (MCS 7522569); \$115,000; 24 mos.

Research will be continued into the basic structure, design, and analysis of computer languages which use two-dimensional input/output, involve context dependent constructs, permit extensible alphabets and user-defined language and graphical constructs, and are user-oriented to the scientific-mathematical-engineering environment. The investigation also concerns itself with the reactive behavior of the user within the man/machine interactive process when an integrated systems approach is used for the design of various input/output techniques of differing efficacy. Concomitant to this research is the automation of those intellectual processes involved in the performance of applied mathematics. Three specific projects contemplated are:

1. Continuation of the research into the computer input of hand-printed mathematical expressions and the optical recognition of typed or printed mathematics. This is relevant to the goal of ultimately automating applied mathematics and direct computer recognition of mathematical text in normal form.

2. Implementation of the Klerer-May programming system at Polytechnic Institute of New York into a "production" system useful to students and faculty. This activity is relevant to further study of the reactive behavior of the user in the environment of such a unique automated programming system.
3. If resources permit, it is planned to continue studies into the operational effects on time-sharing when nonconventional language systems are used. Further results would be relevant to understanding the efficiency of the time-sharing mode.

Stanford University; Robert W. Floyd; Minimal Algorithms, Programming Languages, and Interactive Languages; (MCS 7203553A04); \$61,400; 12 mos.

Research will continue on time/space tradeoffs for deterministic and nondeterministic Turing machines and on methods for top-down syntax analysis with effective error recovery. The conclusion of the implementation effort on the Chiron language is planned.

University of Washington; Irene Greif; A Specification Language for Parallel Processing; (MCS 7612458); \$65,000; 24 mos. (TQ)

The project will develop a specification language suitable for simple, yet precise expression of problems of parallel processing and synchronization. This language will also be of use to a programmer for stating intended meanings of programs which contain positives for parallel computation and for synchronization. Thus this research will be of value in program-writing and program-checking as well as in formal characterization of an area of computation for which only informal problem statements have previously been made.

Four aspects of the research are:

1. The formulation of a semantic model on which to base the language;
2. Development of the specification language;
3. Formulation of proof techniques which facilitate the use of formal problem specifications in program verification;
4. Investigation of solutions to particular problems of synchronization.

Washington State University; David B. Benson; Algebraic Structures in Computer Language Processing; (MCS 7303497A01); \$24,400; 15 mos.

Research in computer programming languages and the computerized understanding of "natural" languages is to extend and deepen the theoretical understanding of these processes. The techniques used are algebraic, relying on categorical algebra, automata theory and formal language theory. Five specific areas being investigated are:

1. Parser Classification and the Algebraic Decomposition of Syntax Categories;
2. Programming Language Semantics;
3. "Natural" Language Understanding Semantics;
4. Syntax-directed translations;
5. Extensibility.

Operating Systems

American University; Walter Jacobs and Martin Freeman; A Model for the Construction of Operating Systems; (MCS 7607682); \$90,000, 24 mos.

A principal lack in current work on operating systems is a concise and comprehensive description of how the system functions. Such a description can be used as the basis for teaching the theory of operating systems as well as for writing them. At the present time, there is a gap between the theory as it is now taught, and the operating systems practice of design and implementation.

The present research will alleviate this problem by developing a model for the construction of operating systems which should be applicable, with at most minor modifications, to a series of computer systems with comparable specifications. The model consists of a policy level, a hierarchy of supervisory levels, and an interface level. The policy level adjusts scheduling rules for the system, the supervisory levels control the scheduling of higher-level system tasks, and the interface contains primitive system routines and a mechanism to control their execution.

The model offers a top-down approach to operating system design that is different from the typical approach based on a hierarchy of virtual machines. It allows both a top-down design and a top-down implementation of an operating system. It will provide a set of operating system primitives suitable for use with operating systems of widely different types.

Brown University; Andries van Dam; Performance Improvement through Function Migration in Distributed Computing Systems; (MCS 7604002); \$293,600; 24 mos.

This research is in the area of improving program performance through distributed computing. Research to date has resulted in a system that allows the programmer to bind the modules of an interactive program to either of two dissimilar processors at run-time in order to optimize cost, response time, resource use, etc. These processors are a large time-shared computer and an intelligent satellite. The methodology allows the programmer to write programs for this configuration as if it were a virtual unprocessor. This view is similar to that of a virtual memory system, which hides the complexities of a memory hierarchy.

The research project will investigate algorithms for automating this runtime distribution process to allow modules to migrate dynamically as a function of processor load. Combinatorial and queueing algorithms for predicting optimal distributions will be studied in conjunction with a team at the University of Massachusetts. Extension of the distribution mechanism to networks of loosely coupled processors also will be investigated.

As a related project, the migration of program functions to optimal levels in a structured hierarchy of levels on a single processor will be studied. Such multilevel migration generalizes traditional two-level migration, that is, the movement of frequently used functions from an operating system or application program into firm-ware. Functions implemented on higher levels incur more overhead but provide more powerful facilities so that complicated trade-offs ensue in assigning functions to levels. Models, principles, and primitives for building such hierarchic systems to facilitate migration and thereby provide optimal performance for a given application system will be developed.

Brown University; Andries van Dam; Distributed Processing (A three-day Workshop), Providence, RI, August 17 to 19, 1976; (MCS 7616569); \$5,000; 9 mos.

An intensive workshop on the topic Distributed Processing will be held. The basic proposition is that no one has defined the term Distributed Processing, and that it is used and even misused for a variety of different purposes. Many other ill-defined and loosely equivalent buzzwords are also in use. Everyone agrees that Distributed Processing is the "wave of the future" without really understanding what it is. Being restricted in their knowledge primarily to

those efforts similar to their own, those who claim to be working in the area rarely know about the work of the many others who also are working in this area. It is imperative to get together a small group of knowledgeable, active, and articulate workers in the field to chart the field and thereby allow the community at large to track and influence future developments in a more organized and productive fashion.

University of California (Berkeley); Alan J. Smith; Software Implications of New Memory Technologies; (MCS 7506768); \$24,000; 24 mos.

Research will focus on policies and software organization that may become feasible with the introduction of new memory technologies (magnetic bubbles and electron beam storage tubes) having different characteristics from conventional memories. For example, new policies might become desirable for updating secondary storage. Moreover, optimal fetch and update policies for magnetic bubble shift registers are not obvious and will be investigated.

State University of New York (Stony Brook); Arthur J. Bernstein and Erlap A. Akkoyunlu; Correctness and Modularity in Asynchronous Systems; (MCS 7604828); \$105,400; 24 mos.

This research will investigate the asynchronous behavior of operating systems, how such systems should be modularized and how their design can be validated. The difficulties involved in making complex, asynchronous systems function reliably are well known. The research is a continuation of the work currently going on at Stony Brook, whose aims are:

1. To develop a framework for the design of such systems which allows a reasonable amount of asynchronism;
2. To take advantage of such a framework in order to develop proof techniques for validating the systems.

Pennsylvania State University; J. L. Bruno and P. J. Downey; Stochastic Models of Job Shop and Operating Systems Scheduling; (MCS 7522557); \$78,500; 24 mos.

A class of sequencing problems which have applications in computer systems will be investigated. The goal is to develop efficient algorithms which determine scheduling rules, optimal with respect to certain performance criteria. Primary concentration is on the mean-weighted-finishing-time criterion (mean time in the system), whose minimization tends to reduce system storage costs due to unfinished tasks resident in the system. Special emphasis is placed on developing new (and stochastic) models for "jobs". The internal structure of a job can be quite complex, consisting of many interacting parts (tasks), stochastic elements and varying resource requirements. A basic model of a job is given and various extensions to the model are planned. Although it is desirable to obtain optimal sequencing algorithms, it is often the case that optimal schedules are computationally inefficient to obtain. In such cases, the concern is with finding fast approximating algorithms for producing schedules provably close to the optimal.

Purdue University; Saul Rosen, Peter J. Denning and Herbert D. Schwetman; Computer Systems Modeling, Measurement and Evaluation; (MCS 7200256A01); \$140,000; 24 mos.

The major goals of this research are to study existing models and to develop new models of the behavior of computer programs and workloads, and of computer systems and subsystems. The aim is to be able to predict, and perhaps eventually to guarantee, performance. The

research includes theoretical analyses of program and system models, and also the study and improvement of data collection and evaluation techniques. Wherever possible, data from real systems are used to calibrate and to validate the models.

University of Washington; Alan C. Shaw; Single Language Interactive Systems; (MCS 7519480); \$88,100; 24 mos.

Research will be carried out in the following areas within the context of single language interactive systems (SLIS):

1. Operating systems design and organization.

An existing systems nucleus will be used as a tool for investigating a variety of possible organizations for dedicated timesharing systems controlling a single language user environment.

2. Path descriptions as a design and documentation tool.

A technique for specifying sequential and concurrent execution paths through software will be further developed and studied as a design and documentation tool. The language processor and operating system of SLIS provide excellent examples to test the path ideas.

3. Graphics facilities in interactive languages.

The PDL picture description language will be investigated further as the graphics part of a general interactive language. Applications are proposed in text and figure formatting and in two-dimensional programming.

Information Retrieval

University of California (Berkeley); Arthur Gill; Research in the Self-Organization of Data Files; (MCS 7615036); \$45,400; 24 mos. (TQ)

This research is concerned with the development of techniques for the automatic organization of data files, and with evaluating the effectiveness of these techniques in search and retrieval operations. Of particular interest here are files in which additions and deletions are relatively rare compared to search and retrieval operations, and where the relative record activities are not known in advance.

University of Michigan; Walter Reitman; Natural Language Communication in a Personal Information Retrieval System; (DCR 7102038A04); \$56,200; 12 mos.

This work is concerned with the mechanisms of human intelligence and natural language communication, and with the design of interactive computer programs that incorporate and utilize analogous mechanisms to improve man/machine communication. Information retrieval and game-playing systems are used as vehicles for the analysis of semantic functions. Procedural representations for recognizing and utilizing local and global patterns and their properties and a perceptual, goal-oriented framework for manipulating these representations have been developed and are being studied.

University of North Carolina (Chapel Hill); Donald F. Stanat; Tree Structures for Associative Searching in Data Retrieval; (MCS 7519681); \$61,700; 24 mos.

Modified forms of binary search trees will be investigated for tasks involving associative searching (sometimes called "retrieval on secondary keys"). These trees are designed for files in

which the records have many keys and searches of the file may specify criteria to be met by arbitrary subsets of key values; thus, any or all of the key values of a given record may be pertinent to a given search. These data structures should make feasible the solution of many problems which have heretofore been computationally intractable, such as various forms of range queries, partial match queries and nearest neighbor searches.

This research will formulate algorithms for file construction, maintenance and searching; these algorithms will be analyzed and their performance investigated experimentally. Variations of the structures will be investigated to determine the suitability of these techniques for similar classes of problems, such as document retrieval.

University of Utah; John M. Smith and Diane C. P. Smith; Optimization Techniques for Relational Data Bases; (MCS 7509903); \$60,800; 24 mos.

To make data base systems accessible to nontechnical users, it is necessary to provide an interface which allows queries to be expressed within a simple conceptual framework. Several types of interface based on a *relational* framework have been developed to provide this capability. However, these interfaces absolve the user of the responsibility for expressing queries which are *efficient* relative to the *actual* physical organization of the data base. It is therefore essential that the interfaces themselves assume the responsibility for transforming the user's high level query into an efficient sequence of primitive data base accesses. This requires the interface to ascertain the overall intent of the user's query rather than provide direct line-by-line interpretation. It is intended to develop and implement such optimization techniques in the context of an interface which provides the user with the power to manipulate large relations as single entities (a relational algebra interface).

Formal Structure of Programs

Duke University; Susan L. Gerhart; The Derivation of Programs from Organized Knowledge Bases; (MCS 7508146); \$68,800; 24 mos.

A new method of program construction called *program derivation* is suggested. Bodies of programming knowledge are collected and organized into knowledge bases of schema (abstract programs) and transformations of schema which serve as handbooks for guidance in constructing reliable programs. A program derivation is a sequence of steps where schema from the knowledge base provide initial programs which can then be transformed and combined into complete, efficient, and correct programs. Along with each schema and transformation are premises which are sufficient for the correctness of any program resulting from a derivation. Knowledge bases are acquired empirically by generalizing from example programs and their derivations.

The research is motivated by the need to factor the task of proving program correctness in two ways: (1) separating the general correctness of frequent and useful patterns in programs (schema and transformations) from the correctness of specific instances of these patterns (programs in a derivation) and (2) proving a relatively simple, but possibly inefficient, program and then improving it by optimizing source-level, correctness-preserving transformations.

An interactive system will be developed which will permit a programmer to direct a derivation while the system does all necessary record-keeping and text-manipulation. An equally important part of the research is to use the system for the acquisition of knowledge about several domains of programming.

New Mexico State University; John B. Johnston; Semantic Modeling of Computational Systems; (MCS 7515997); \$45,000; 24 mos.

This research will develop conceptual and concrete versions of a simple, transparent, widely applicable model of computations and computational systems useful for comparative evaluation and improved design of computer architectures and languages. The model will aim at explication of sequential control computations and their interactions in a segmented memory context: peripheral computations, nucleus operating system computations, and nested declaration central computations.

Purdue University; Maurice H. Halstead; Basic Relationships Governing the Implementation of Computer Programs; (MCS 7605611); \$80,000; 24 mos.

Experimental and theoretical investigations have produced results that offer quantification and prediction of components of the process of computer program implementation. Predictions have been made of programming rates and error rates in several languages. Further study is investigating the expectable accuracy and the limits of applicability of the relations that have been discovered.

University of Southern California; Ellis Horowitz and John V. Guttag; Improved Software Reliability via Axiomatic Specification of Data Structures; (MCS 7606089); \$72,700; 24 mos.

This study is concerned with developing improved techniques for design and verification of software. In particular, concentration is on the design of data structures, which are an integral part of every software system. The point of view is to first develop a notation for rigorously specifying a data structure without implying anything about its eventual representation in a computer. This has the advantage of allowing the designer to concentrate on each task separately, thus controlling the complexity of the process and hence improving the reliability of the end result. This kind of specification can also be instrumental in proving the correctness of an implementation of the design, thus providing a second advantage to this approach.

Stanford University; Donald E. Knuth; Analysis of Algorithms; (MCS 7203752A03); \$107,200; 12 mos.

A program of research in the analysis of algorithms is to be continued. The research is oriented towards an improved quantitative understanding of the fundamental algorithms of computer science and is a continuation of similar, previously supported work.

The study of the construction of algorithms, the application of algorithmic processes, and empirical studies of problems in analysis and construction are deeply connected with combinational and discrete mathematics which will be emphasized in the coming year.

Syracuse University; John C. Reynolds; The Design, Definition, and Implementation of Programming Languages; (MCS 7522002); \$129,100; 24 mos.

Research is to be conducted on the mathematical semantics of programming languages and its application to language design. Specific topics include: the unification of algebraic and lattice-theoretic semantics, representation theorems for the typed lambda calculus and their application to the definition of heterogeneous algebras, the use of type-binding to provide polymorphic functions and user-defined types, direct, continuation, and process semantics of Scott's lattice of flow diagrams, direct and continuation semantics of type-free lambda calculus, memory-free semantics of Algol-like languages, semantics for determinate parallelism, and the design and definition of a new general-purpose programming language.

University of Texas (Austin); Terrence W. Pratt; A Formal Theory of Programming Language Definition; (MCS 7516858); \$55,500; 24 mos.

A complete formal theory of programming language definition has been developed under NSF grant support over the past five years. The formal definition technique has been shown to be a practical method for the definition of actual programming languages and has also led to new insights into the structure of programs and programming languages. This award will allow a deeper investigation of the relation of the definitional technique to axiomatic definitions, and a deeper investigation into a promising new technique for the analysis and optimization of programs developed earlier. Related work in language specification for the user and in the formal analysis of program control structures will also be carried out.

University of Washington; Robert G. Herriot; Semantic Modelling of Programming Languages; (MCS 7501308); \$43,800; 24 mos.

This award continues a project to explore an operational model of the semantic definition of programming languages. The model, combining both programmatic and graphic notation, is being used to describe recently proposed languages (SMALLTALK AND PLASMA) to study both the adequacy of the model and the completeness and consistency of the languages. The model is to be used as the basis of a language-processing system intended to allow a user to define or extend a language by supplying patterns and associated semantics.

Symbolic and Algebraic Manipulation

University of Illinois (Chicago Circle); Vera Pless; Investigation of Computer Algorithms; (MCS 7603143); \$21,700; 12 mos. (Supplement: \$16,300 - total grant, \$38,000)

Research will continue in four areas for which substantial progress has already been made. The first area is the development, testing and implementation of new and presently known algorithms for handling finite groups on computers when the groups are given in terms of generators and defining relations, generating permutations, or generating matrices.

This would include an algorithm for finding subgroups of any given index in a group given by generators and relations and new algorithms for finding presentations of permutation groups which cannot be found at present. The second is the study of efficient computer algorithms for combinatorial configurations such as algebraic codes and graphs. The third area is the investigation and construction of good algorithms for the action of groups on such structures. Here work will continue on vector orbits and set stabilizers. Fourth, the development of the computer system, CAMAC, will be continued.

University of Illinois (Chicago Circle); Vera Pless; Groups, Codes and Computers; (MCS 7603143A02); \$3,400; 0 mos. (TQ)

This is a supplement to grant MCS-7603143, to permit the visit of Professor John H. Conway to the University of Illinois at Chicago Circle.

Professor Conway visited Circle in November 1975, and at that time started working with Professor Vera Pless on the problem of classifying all $(32,16)$ self-dual codes. In December he wrote a letter to Professor Frederick Smith of Circle answering, in part, Professor Smith's questions about Norton algebras which Conway discussed in his lecture at Circle. Professors Frederick Smith and Steven Smith (also of Circle) have both been stimulated to work further on these new algebras associated with the new sporadic simple groups. Professor S. Smith has just sent Professor Conway a paper with his latest results on these topics. In addition to this,

Professor Conway shares many interests with other faculty members at Circle, namely Professors Oliver Atkin, Paul Foulser, Norman Hamilton, and Noboru Ito, among others. He would also contribute to the Chicago mathematical community outside Circle, since this is one of the areas in the country which is very strong in finite group theory.

Rensselaer Polytechnic Institute; Bobby Forrester Caviness; Algorithms for Transcendental Functions Arithmetic; (MCS 7623762); \$71,100; 24 mos. (TQ)

The program of research consists of five sub-programs:

1. Generalization of algebraic independence results for nonelementary transcendental functions;
2. Applications-oriented interpretations of algebraic independence results;
3. Computational complexity of symbolic mathematical computation problems;
4. Extension of the Risch integration algorithm to nonelementary classes of functions; and
5. Transcendental number arithmetic.

The execution of this research should significantly extend the frontiers of knowledge related to methods for performing exact, symbolic mathematical calculations on classes of transcendental functions that frequently occur in applied mathematics.

University of Wisconsin (Madison); George E. Collins; Algebraic Algorithms and Systems; (MCS 7413278A01); \$57,800; 24 mos.

This research includes:

1. Continued development, implementation and improvement of the Collins quantifier elimination algorithm;
2. Continued development, implementation and improvement of various subalgorithms required by the quantifier elimination algorithm;
3. Experimental application of the quantifier elimination algorithm to select problems;
4. Study of special cases of the quantifier elimination algorithm;
5. Study of polynomial factorization algorithms; and
6. Research on the exact calculation of the complex zeros of polynomials.

Program Verification

Stanford University; John McCarthy and David C. Luckham; Verification Oriented Programming; (MCS 7600327); \$160,000; 24 mos.

This research is directed towards the eventual development of interactive systems to provide on-line aid in the construction and verification of programs. Areas covered include:

1. Design of assertion and program specification languages;
2. Definition of verification-oriented proof rules for programming languages;
3. The proof theory of the logic of programs;
4. The development of standards and methodology for simultaneously writing, documenting and verifying programs;
5. Experimentation with a prototype verification system.

The work concentrates on extensions of the Pascal programming language.

Specific areas of application include operations on data structures involving pointers and records, programs containing concurrent processes, and complexity of computations.

University of Texas (Austin); Raymond T. Yeh, Sanat K. Basu and Jayadev Misra; Studies on the Theoretical Basis of Program Provability; (DCR 7509842); \$82,000; 24 mos.

This research is motivated by the recognized inadequacy and lack of theoretical basis for the understanding of provability of program correctness. It is intended to investigate fundamental questions concerning conditions for provability of program correctness, and their ramifications in hopes of developing a theoretical foundation to support existing or new proof methodologies.

Specific goals of the proposed research are listed in the following:

A. Provability of Program Correctness

1. To investigate conditions for program provability;
2. To develop methodology for semantic structuring of programs;
3. To characterize a class of programs amenable to mechanical assertion generation.

B. Development of a New Proof Methodology and Its Supporting Theoretical Basis

1. To study formal properties of semantic transformers;
2. To investigate the nature of extension of the first order logic for a deductive system necessary to prove theorems about structured programs;
3. To develop an algebra of iterated substitution operators and to study its applications to the proposed verification method for programs with a depth of nesting of do-while loops exceeding one;
4. To investigate the effective use of incomplete information about loop invariants in the construction of semantic transformers;
5. To develop a systematic method for the generation of loop invariants (when such exist).

COMPUTER SYSTEMS DESIGN

Computer System Architecture

University of Arizona; Fredrick J. Hill; Digital Design Language Research; (MCS 7523250); \$63,700; 24 mos.

The focus of this research is on comparing two different design languages approaches for several design problems. In addition, an existing Hardware Design Language (AHDL) will be improved and extended and used to generate designs utilizing Medium and Large Scale Integrated circuits as building blocks. Emphasis will be on portability, flexibility, and ease of design.

University of California (Irvine); Arvind, and Kim P. Gostelow; A Computer Capable of Exchanging Process Elements for Time; (MCS 7612460); \$12,600; 3 mos.

With the advent of LSI technology large numbers of inexpensive processors have become available, yet the ability to realize the full potential of this technology has fallen short. A primary reason for this failure has been due to an inability to move beyond the sequential control structure of conventional programming languages. The notion of a sequential and/or centralized control for a machine composed of large numbers of processing elements severely restricts the design and complexity of possible computer architectures. Data flow languages provide an alternative base machine language more suited to a technology (such as LSI) which favors distributed processing.

The objective of the research is to formulate and evaluate (by simulation) a machine whose design is based on a new technique of interpreting existing data flow languages. The most significant and distinguishing aspect of this new scheme of interpretation is that it permits a literal exchange of processing elements for computation time, in a very general and mechanical way. An architecture based on the new interpreter will allow a computation to unfold and spread dynamically over a space of processing elements. The machine also has the capability of partitioning itself into disjoining domains of activity, each domain corresponding to the execution of a distinct process.

University of California (Irvine); Arvind, and Kim P. Gostelow; A Computer Capable of Exchanging Processing Elements for Time; (MCS 7612460A01); \$88,700; 21 mos. (TQ)

This is an amendment to research previously supported. The description of the project remains the same as that described above.

Carnegie-Mellon University; Daniel P. Siewiorek; Register Transfer Level Computer Systems Design; (MCS 7203636A04); \$85,900; 12 mos.

Register transfer (RT) level logic design centers in three areas: Representational Methods, Design Algorithms and Computer Modules (CMs). In the area of Representational Methods this project will assist in the development of a hardware description language employing concepts of structured programming. The new language will be more of a design aid than existing languages. The group will also assist in developing extensions to the Instruction-Set Processor (ISP) computer description language. These extensions will facilitate module set description and the automatic generation of assemblers. In the area of Design Algorithms, effort will focus on: (1) more sophisticated design heuristics which can reduce the number of alternate designs which must be considered within the computer assisted design systems; (2) module set relative design;

and (3) bus design. In the area of Computer Modules a ten processor CM system is scheduled for completion. The system will be evaluated along performance, reliability, and flexibility dimensions.

University of Colorado; Gary J. Nutt; Array Processor Evaluation; (MCS 7408328A01); \$75,700; 24 mos.

The complexity of modern-day computing systems makes the study of measurement and evaluation techniques an important component in designing, turning, and understanding these systems. In this work, the attention is focused on measurement and evaluation techniques as applied to associative and array processor systems, using simulation as a medium of study. The particular topics to be considered include user oriented measurements, system measurements, and the development of monitoring tools to accomplish these measurements.

University of Illinois (Urbana); Edward S. Davidson; Parallel Computer Systems Architecture; (MCS 7303488A01); \$115,700; 24 mos.

This research is concerned with the design, control, applications, and efficiency of pipelined processors. Interest in the problem is spurred by the inherent economy of pipelining over other methods of performance enhancement and by the need for higher performance processors and processor-memory organizations to work in balance with newly available high-bandwidth, low-cost semiconductor memory components and many-way multiplexed data sources.

This research focuses in two areas:

1. Work on buffering in pipelines, modeling and control of multifunction pipelines with shared resources, and searching algorithms for parallel-pipelined processors, and
2. Completion of recently begun studies of processor-memory architecture for highly parallel systems including separate studies of primary memory organization, virtual memory management, and processor organization, with follow-on studies devoted to unifying these results from a total system viewpoint.

University of Illinois (Urbana); David Kuck; Computer Hardware and Software Organization; (MCS 7307980A03); \$223,900; 24 mos.

This grant supports several theoretical and practical aspects of computer system organization. A machine simulator, fed by a program analyzer, is to be utilized. The analyzer discovers independent tasks as a compiler would. The simulator can be used to represent various pipelined and parallel machines — memories, switches, and processors being handled independently. Thus, the speeds and costs of a great variety of configurations can be studied. A number of abstract machine design questions, including combinational circuit synthesis, parallel memory systems and alignment network theory, are being explored.

Another area to be investigated is that of file-processing machines. This work involves the abstract analysis and simulation of memory hierarchy performance. Moreover, various merge networks which preprocess data between the disk and main memory are being explored. The EUREKA information retrieval system forms the basis of practical studies of user behavior. Using various system features, students are being tested and their ability to study large amounts of text, including tabular material, is being measured. Based on these studies, new machine organizations will be configured and analyzed.

Iowa State University; Roy J. Zingg and Robert M. Stewart; Time-shared Computer Systems Research; (MCS 7203642A04); \$161,700; 12 mos.

The SYMBOL IIR experimental computer system embodies advanced and novel architectural concepts. This system is now located at Iowa State University. The objectives of this

research project are to evaluate the present system formulation and its underlying assumptions, and to extend and/or reformulate the system on the strength of the evaluations.

This research will focus on three areas: controlled sharing of memory, resource management, and language structure. In addition, an effort will be made to sum up the results of this project and to separate concepts from their particular implementation in the SYMBOL IIR computer system.

University of Iowa; Amar Mukhopadhyay; Parallel Processing, Multiprocessing and Computer Organization; (MCS 7604763); \$75,300; 24 mos.

This research project focuses on deterministic scheduling of multiprocessor computer configurations. Specifically, problems associated with scheduling of independent task systems on arbitrary number processors and generalized task systems with low execution time and small number of processors and with tree-like precedence graphs will be considered. The nature of the complexity of the scheduling algorithms in relation to the notion of polynomial completeness will also be studied.

In addition, parallel evaluation of arithmetic expressions in which non-uniform execution times are assumed will be considered.

University of Massachusetts (Amherst); Harold S. Stone; Computing Systems with Multiple Processors; (MCS 7611650); \$72,500; 24 mos. (TQ)

This project will investigate three aspects of multiple processing systems. The first is directed toward automatic load-sharing in a network of computers. The idea is to assign program modules automatically to processors such that the global computation proceeds at the fastest possible rate, with due consideration given to the current processor loading and the cost of processor-to-processor communication delays.

The second investigation is aimed at increasing the versatility of a single-instruction-stream processor by making it possible to break up a single-instruction-stream computation into several multiple-stream computations, which may then rejoin under program control at a later time. This capability enables a computation to make efficient use of vector-mode operations when needed, yet still have the generality of the multiprocessor for the unstructured portions of the computation.

The third investigation is aimed at the analysis of several algorithms that appear to be best suited for multiple processors. The object is to identify bottlenecks in the computations due to processor interlocks, multiprocessor overhead, and queueing delays. From these analyses it is hoped that general methodology for running algorithms efficiently in a multiprocessor environment can be developed.

University of Southwestern Louisiana; Bruce D. Shriver; Development of a Systems Implementation Language for Realizing Virtual Systems; (MCS 7601661); \$35,500; 24 mos.

Microprogramming requires careful planning because it involves machine dependency, concurrency recognition and special-purpose control structures. This research addresses a transportable, high-level language and its translator for the production of high-quality microprograms. This is done by extending an existing systems programming language. The extended language is translated into an intermediate hypothetical host language called IML. The IML is reduced to a machine-dependent form by writing semantic macros that complete the translation. The IML must be carefully designed to include features of a broad class of host machines. The IML semantic routines must be of sufficient power and versatility to generate efficient code for a variety of host machines. Transportability is accomplished through the use of a generalized IML.

Stanford Research Institute; Marshall C. Pease; A Study of Large-Scale Microprocessor Arrays; (DCR 7408910A01); \$97,700; 24 mos.

This research will be directed toward the study and evaluation of large-scale microprocessor arrays. Topics include: (1) a study of the relative advantages and disadvantages of various array configurations, (2) a study of algorithms which might be useful in array architecture, and (3) the development of logic specification of the essential modules of various arrays.

University of Washington; Jean-Loup Baer; Modeling of Parallel Processing; (MCS 7609839); \$73,400; 24 mos. (TQ)

This project will investigate several aspects of parallel computer structures. They will explore uses of Petri nets and possible extensions needed in order to be able to model the computer control structures needed in a parallel environment. Data structures will be considered in an attempt to make them more amenable to concurrent processing. In addition, algorithms which are more convenient and efficient to process these data structures will be investigated.

Fault Tolerance and Reliability

University of California (Los Angeles); Algirdas A. Avizienis, Wesley W. Chu and David Martin; Fault-Tolerant Computing; (MCS 7203633A04); \$208,200; 12 mos.

This project is a continuing research effort focused on fault-tolerance of computer systems. A fault-tolerant computer executes its entire set of programs correctly in the presence of faults in the computer system. Faults which occur in a computer system fall into two major categories: hardware faults which include all deviations from design-specified values of logic variables within the hardware of the computer; and software faults which include all deviations from correct program execution due to errors occurring during the translation of the original specification of an algorithm to the program being executed.

The primary topics of study include: Methodology of Fault-Tolerance, Design and Modeling of Fault-Tolerant Computer Systems, and Software Reliability.

Stanford University; Edward J. McCluskey; Reliable Computers; (MCS 7605327); \$58,600; 12 mos.

This research is aimed at developing both a basic understanding of and the techniques for designing reliable computers. The research will be focused on: (1) development of techniques for random testing, test set generation, and compact testing using the techniques of signal reliability developed under a previous NSF grant; (2) modeling the effects of transient and intermittent faults using signal reliability techniques; (3) study of the effects of error latency on self-checking circuits; and (4) study of fault properties with emphasis on special network structures such as iterative networks, symmetric networks, etc.

Computer System Performance Measurement and Evaluation

Columbia University; E. G. Coffman, Jr.; Research in Resource Allocation Problems of Computer Systems; (MCS 7619576); \$76,100; 24 mos.

This research continues the formal treatment of resource allocation problems in large computer systems. The approach is one of mathematical modeling. Through the application and extension of classical methods, the synthesis and analysis of efficient sequencing, storage allocation, and register allocation algorithms using both deterministic and stochastic models where appropriate will be studied.

The benefits hoped for are three-fold: (1) the synthesis of more efficient techniques in computer resource management and the insights to be expected from analyses of these and currently proposed techniques, (2) a coherent formulation of operating system sequencing and control problems for use in university computer science curricula, and (3) extensions to the relevant mathematical disciplines in the hope that future approaches to related problems can be simplified.

University of Massachusetts (Amherst); Walter H. Kohler; Queueing Models for Distributed Computer Systems; (MCS 7603667); \$45,400; 24 mos.

The availability of low-cost minicomputers and microprocessors has generated interest in the design of multiple processor computer systems in which the control, storage, and execution of program and data modules are dynamically distributed over a network of processors. However, except for the implementation of several special purpose prototype systems, very little is known about distributed system design. Queueing models have proved helpful in the design and analysis of time-sharing systems, communications networks and memory sub-systems, but the existing techniques for networks of queues are not adequate to model distributed systems.

The goals of this research are to develop solutions for open and closed queueing models of multiple processor distributed computer systems and to analyze, evaluate, and validate such models. The models will include state-dependent routing policies and service rates. Closed-form expressions for the equilibrium state probabilities and various system performance measures will be sought, but numerical methods and simulation will be used where analytical solutions prove to be intractable. Models will be developed for prototype systems such as the two-processor host/satellite graphics system under development at Brown University. Once validated, these models will be used to analyze various scheduling and allocation policies with the results fed back for implementation.

Pennsylvania State University; E. G. Coffman, Jr.; Research in Resource Allocation Problems of Computer Systems; (MCS 7101944A03); \$14,100; 4 mos.

This research continues the formal treatment of resource allocation problems in large computer systems. The approach is one of mathematical modeling. Through the application and extension of classical methods, the synthesis and analysis of efficient sequencing, storage allocation, and register allocation algorithms using both deterministic and stochastic models where appropriate will be studied.

The benefits hoped for are three-fold: (1) the synthesis of more efficient techniques in computer resource management and the insights to be expected from analyses of these and currently proposed techniques, (2) a coherent formulation of operating system sequencing and control problems for use in university computer science curricula, and (3) extensions to the relevant mathematical disciplines in the hope that future approaches to related problems can be simplified.

Graphics and Input/Output Research

Cornell University; Donald P. Greenberg; Development of Computer Graphic Techniques and Applications; (MCS 7414694A02); \$196,300; 18 mos. (TQ)

Cornell University is implementing a computer graphics facility for use by the campus research community. This project involves research on advanced graphics techniques, especially involving improvements in the production of half-tone images, for research applications. Major emphasis will be placed on improvement of techniques for handling hidden lines and planes, and techniques for graphical input.

The result should be usable software and hardware which will improve the efficiency of the present picture generation technology.

North Carolina State University; John Staudhammer and James W. Gault; Color Computer Graphics; (MCS 7506599); \$140,600; 27 mos.

The primary areas of research are:

Interactive graphics language: The thrust of this research is to investigate the nature and structure of a language which will facilitate man/machine interaction in an interactive color graphics environment.

Computational Models: The research will focus on the investigation and definition of computational models which, when coupled with the language, allow efficient and near-real-time manipulation of complex structures.

Logic Design and Major Subsystems

University of Illinois (Urbana); Saburo Muroga; Logical Design Theory for Integrated Circuit; (DCR 7303421A01); \$71,300; 24 mos.

Logical design is getting enormously complicated because many Integrated Circuit (IC) logic families are available and problems other than pure implementation of switching functions, such as ease of test or redesign, must be considered. Compact network implementation of a switching function is important in the case of integrated circuit logical design, since a smaller IC chip area is cheaper because of higher production yields.

This project is exploring logical design procedures for integrated circuits, particularly Metal Oxide Semiconductor (MOS) and Integrated Injection Logic (IIL) circuit families. Included is a study of the design procedures for multiple-output networks for incompletely specified functions and a study of the optimal design of Programmable Logic Array (PLA) networks.

Other

University of Illinois (Urbana); David J. Kuck and Edward C. Kalb; Symposium: Computer and Algorithm Organization at University of Illinois, Urbana, Illinois, Spring 1977; (MCS 7610823); \$9,600; 18 mos.

This conference on "Computer and Algorithm Organization" will be held at the University of Illinois at Urbana-Champaign in the Spring of 1977. The conference will bring together people working on machine organization, software and algorithms—something that ordinarily does not happen at conferences.

Two experts in each of the three areas will be invited to write papers which survey their areas of interest and also point out some problems for the future. An additional number of speakers will be chosen on the basis of submitted papers. The invited papers and the submitted papers (or their abstracts) will be published in the conference proceedings. This resulting volume should provide a good survey of the field and be of value to students, researchers and machine designers.

TECHNIQUES AND SYSTEMS

Data Acquisition and Analysis

University of California (San Diego); Kent R. Wilson; Research on Computer Systems with Tactile Input; (MCS 7505810A01); \$55,000; 12 mos.

This project focuses upon providing modes of tactility as part of the scientist's computer research laboratory. It opens the way to a new mode of Turing-machine problem-solving which in turn implies a different computer architecture. Tactility opens the possibility of the human steering of very complex calculations in an on-line fashion, effecting a man/machine symbiosis which can attack problems now far too complex even for the fastest processors. The project concentrates upon the potential of such a facility for chemistry and molecular biology, but also noted is its relevance for research and learning in the areas of computer science, engineering, design, physics, biology, medicine, psychology, education, art, and insight for the blind.

Carnegie Mellon University; Charles M. Eastman; A General System for Computer-Aided Design; (MCS 7303492); \$42,500; 7 mos.

This is the third year of a three-year project encompassing efforts to provide an improved theoretical base for integrating computer aided design (CAD) functions and to explore techniques to facilitate interactive manipulation of large data bases by designers.

A data structure has been created for defining and manipulating elements of arbitrarily complex shape and a data base has been designed for storing and manipulating large numbers of elements. The principles have been incorporated into a program called Building Description System, which runs on a PDP-11/15. Algorithms for mapping from a spatial domain to elements within it have also been implemented and compared.

The focus for the remaining term of the grant will be upon the implementation and testing of the design language and data base facilities implemented on the PDP-11. Also planned is a two-day workshop on design information systems that will include demonstrations of the Building Description System.

University of Chicago; Anthony Robertson; Computer Analysis of Moving Images on Film; (MCS 7522362); \$55,200; 12 mos.

This project involves research on computer analysis of dynamic systems which have been recorded on film. The approach taken enables the user to select elements in a film, as it is being projected, for digitization into computer-accessible form. The computer accepts the digitized information and, from the (x,y) coordinates, calculates serial positions, displacement with time, velocities, etc., playing back a kinegram of the selected data. The kinegram is compared with the original film and adjusted as necessary, allowing feedback between the computer and users to make accurate data collection more efficient. All devices, including the film projector, Graf-Pen and visual display are to be computer controlled, allowing easy monitoring of all variables such as frame number, film speed, etc. Statistical calculations on the stored data will also be possible.

Massachusetts Institute of Technology; Barry L. Vercoe; Man-Computer Interaction in Creative Applications; (MCS 7610152); \$92,000; 15 mos.

A computer-based system that realistically matches the context-switching and parallel processing of human creative activity is the focus of this research. Much computer-assisted work suffers from a low bandwidth of communication which almost eliminates an environment that fosters creativity. This system is directed toward the provision in parallel of a range of

communication modes, including a facility for the creation of complex networks of signal processing routines by the movement of symbolic flow diagrams on a CRT. The system is being organized around AMBL, a class-structured "active object" language, and its "test-bed" will be music composition, a creative activity entailing a complexity of signal processing and signal representations.

State University of New York (Stony Brook); George W. Stroke; Holographic Research (Optical Computing) on Three-Dimensional Reconstruction in X-Ray Crystallography; (MCS 7611010); \$51,100; 12 mos.

Recently there have been new developments in *two-dimensional* holographic image processing and reconstruction which are likely to make a significant contribution in *three-dimensional* reconstruction in X-ray crystallography. This project is directed toward research on the theoretical and experimental foundations for a holographic solution of 3-D structure reconstruction problems, with particular reference to X-ray crystallography. Based on new principles, the method should permit reduction of the usually very laborious 3-D digital Fourier-transform computational problem to a set of 2-D Fourier transformations carried out optically. The planned implementation makes use of the principles of holography and of optical computing.

Stevens Institute of Technology; Stephen D. Shapiro; Transform Methods for Curve Detection in Pictures; (MCS 7608176); \$60,500; 24 mos.

This work will investigate the transform method for curve detection in pictures. Global, Hough-like, transforms are applied to feature points of digitized pictures. Analytical properties of these transforms will be sought to determine the conditions under which they are applicable and how they may best be utilized. Their properties will be treated in the presence of noise, distortion, approximate knowledge of the sought-after curve family and for the case of multiple curve families. These properties will be used to predict transform performance.

Graphics Techniques

Cornell University; Donald P. Greenberg; Development of Computer Graphic Techniques and Applications; (MCS 7414694A01); \$182,500; 12 mos.

Cornell University is implementing a computer graphics facility for use by the campus research community. This project involves research on advanced graphics techniques, especially involving improvements in the production of half-tone images, for research applications. Major emphasis will be placed on improvement of techniques for handling hidden lines and planes, and techniques for graphical input.

The result should be usable software and hardware which will improve the efficiency of the present picture generation technology.

Massachusetts Institute of Technology; Nicholas Negroponte; Machine Recognition and Inference Making in Computer Aids to Design; (DCR 7522565); \$216,600; 12 mos.

This effort is directed toward machine understanding of human graphical expression, using as a vehicle the goal of personalized architectural design by laymen. Basic work in graphic input techniques and complex graphic description will be done to provide the foundations for further efforts toward this goal. The project includes a component of psychologically oriented experimentation on human sketching techniques and mannerisms.

Massachusetts Institute of Technology; Nicholas Negroponte; Machine Recognition and Inference Making in Computer Aids to Design; (MCS 7420974A02); \$220,200; 12 mos. (TQ)

This is a continuation of research previously supported under MCS 7420974A01.

This research is directed toward machine understanding of human graphical expression, using as a vehicle the goal of personalized architectural design by laymen. Basic work in graphic input techniques and complex graphic description provides the foundations for this effort. The project includes a component of psychologically oriented experimentation on human sketching techniques and mannerisms.

Ohio State University; Charles A. Csurí; Real-Time Animation as a Tool for Research; (DCR 7400768); \$55,600; 12 mos.

This project, involving research on real-time computer graphic animation and several research applications, is in its third year. Software is being developed to enhance the support of graphics operations by a standard operating system (RSX-11D), to implement a graphics support system, and to implement efficient algorithms for hidden line and surface removal. A graphics programming language is in the final design phase. New techniques for data generation are being explored. An experiment on perception of motion is in progress. A film describing this research is nearly complete. The major efforts in the coming year will focus on the language project and data generation techniques. Research applications will be explored, notably in astronomy, psychology and education of the handicapped.

University of Pennsylvania; Norman Badler and Stephen Smoliar; Techniques for the Representation of Movement-Related Information Using a Digital Computer; (MCS 7619464); \$90,000; 24 mos. (TQ)

The long-range goal of this project is computer recognition and description of patterns of human movement. As a step toward that goal, research is being conducted on a computationally suitable notational system to serve as a low-level language for description of human movement. The notational system is event-oriented, rather than time-interval oriented, and the events themselves are primarily symbolic, rather than numeric; that is, significant events are indicated by changes in semantic relations rather than in numerical quantities. A related focus is the design and implementation of data and control structures appropriate to the description and manipulation of information related to human movement which may then provide a basis for an appropriate low-level programming language. This research on the representation of movement is intended to serve as a flexible medium which may be adapted to many different applications. On the one hand, existing notational systems and, eventually, direct visual input can be translated into an internal representation based on the data and control structures resulting from this research; on the other hand, movement information can be retrieved from these structures.

Stanford University; Ronald N. Bracewell; Maximum Entropy Techniques for Digital Image Reconstruction from Projections; (MCS 7612456); \$50,000; 12 mos.

This project is concerned with research on improved image reconstruction techniques. In a number of important situations the domain over which data can be collected is defective by comparison with what would ordinarily be desired. In the field of X-ray imaging the data may be imperfect when moving objects such as the heart are to be imaged or when it is necessary to limit the X-ray exposure to the patient. Analogous cases arise in other fields such as astronomy, geophysics, and electron microscopy. A new technique, maximum entropy image reconstruction, appears capable of high-quality reconstruction despite missing data. Maximum entropy procedures have been used for reconstruction in the radio astronomy context of Fourier

synthesis, and have provided experience with various mathematical expressions for "image entropy" that might correspond to the sharply defined concept of entropy in physics. It is the suitability of these techniques under the different circumstances peculiar to radiographic reconstruction that will be investigated.

State University of New York (Buffalo); Gabor T. Herman; Graphics and Microprogramming in Image Reconstruction; (MCS 7522347); \$65,300; 12 mos.

The computer technology used in presently announced transaxial tomography devices is too primitive to handle, in a feasible period of time and at a feasible cost, data obtained either from rapidly moving objects (heart) or large amounts of data covering the whole extent of a big organ (lungs), and to display the results obtained from such data in a truly effective way. Aspects of these problems will be addressed by this research, concerned with the implementation of an operator-interactive computer graphics systems and with the use of micro-programmed specialized functions for the reconstruction problem. Cooperation with the Mayo Clinic on the design of a dynamic spatial reconstructor for the study of cardio-pulmonary disabilities and on early detection of cancer lesions will provide immediate medical applications of this work.

Hierarchical Systems

Purdue University; Rodney B. Harrington and Ronald L. Geise; MIRACLE II, A Hierarchical Interactive Data Acquisition System; (DCR 7419493A01); \$74,500; 12 mos.

The MIRACLE hierarchical computer system at Purdue serves a multidisciplinary research community. It stands as one of the more successful demonstrations of hierarchical computing facilities, enabling a central time-sharing system to serve on-line real-time experiments in laboratory and field stations. Plans for further development include joining the RSTS-11 time-sharing operating system in one computer with an RSX-11 event-driven operating system in another computer (both PDP-11/45's) so that an experimenter will have access to either system from his laboratory terminal. Further system and technique development will be undertaken in support of a prototype experiment in on-line closed-loop control of an animal's environment based on measurements of its physiological state.

Modeling

University of Arizona; Willis E. Lamb, Jr.; Computer Studies in the Physics of Non-Equilibrium and Related Processes; (MCS 7604127); \$89,300; 12 mos.

A computer is used to treat several important problems in theoretical physics. These include:

1. The Fermi-Pasta-Ulam problem in nonlinear crystal lattice dynamics, and in non-equilibrium statistical mechanics;
2. Multimode laser theory;
3. Nonlinear amplification of incoherent radiation;
4. Solution of time-dependent Schrodinger equations for perturbed atomic systems;
5. Isotopically selective dissociation of a polyatomic molecule by high-power laser radiation, treated as a classical n-body problem.

These problems all involve the solution of large systems of coupled nonlinear differential equations. A recently introduced minicomputer which has the speed, core size and convenient

output peripherals to deal with problems of the contemplated magnitude will be utilized. Where appropriate, it is intended to make use of the methods of slowly varying amplitude and phase before beginning the numerical work.

University of Arkansas; James E. Dunn; An Interactive, Multivariate Statistical Data Analysis System for Research in Ecology; (MCS 7513696); \$20,200; 24 mos. (Joint support with Ecology Program — total grant, \$40,400; 24 mos.)

This project is directed toward the incorporation of existing multivariate statistical data analysis computer programs into a unified, user-interactive computing system. Though the guiding criterion for inclusion of any procedure in the system will be its past applicability for research in ecology, the system will have important applications in any field, such as psychology, sociology, and anthropology, which frequently gives rise to multivariate data.

Recognizing that the typical user is only an occasional user whose long-term retention of typical instruction manuals is likely to be poor, the design of the system will be luxurious in the following sense: By taking full advantage of the user-interactive capability of modern computer hardware, the computer will supply essentially all of the instructions to the user, including available options, at relevant times during the course of the analysis. Questions and interpretations, as typically supplied by a consulting statistician, will appear at appropriate places. Graphics capability, both on and off line, will be available on command.

Distribution of the system, once complete, will be on a cost basis by the Statistical Laboratory, with the assistance of the University of Arkansas Computing Services.

California Institute of Technology; Gilbert D. McCann; A Program to Develop a Generalized Method of Modeling Nonlinear Biological Systems; (MCS 7303391A02); \$40,600; 12 mos.

This is a continuation of the study of the application of white noise stimulation and Wiener kernel filtering to nervous system signal analysis and modeling.

The work includes extensions of identification theory and development of a comprehensive system analysis based on the theory; development of an effective generally available, interactive computer system for this; and a feasibility study (and possible development of a prototype) for a cheaper, more rapid and more accurate hybrid (analog/digital) device for computing the identification models.

Illinois Institute of Technology; Peter H. Greene; Distributed Task Organization for Computer Networks; (MCS 7601310); \$80,000; 24 mos. (Joint support with Networking for Science Program — total grant, \$190,600; 24 mos.)

This research is directed toward extending the range of utilization of networks of very small computers. The work to be done includes studies in the requisite mathematical theory, the generation of programming techniques for loosely-coupled procedures distributed over a network and for their parallel operation, as well as tests of the resulting methods in a microcomputer network.

The results of this work should provide a base on which to enlarge the intelligent systems type of microcomputer utilization.

University of Michigan (Ann Arbor); Arthur W. Burks and John H. Holland; Formal Theory of Multi-Dimensional, Nonlinear Systems, with Interdisciplinary Applications; (MCS 7604297); \$277,700; 36 mos.

This research focuses on the intensive application and continued development of a general theory of multi-dimensional, nonlinear dynamic systems. Emphasis will be placed on a variety

of difficult interdisciplinary problems which presently lie beyond the standard analytic repertoires of both mathematics and the computer sciences.

The modeling and simulation theory will include work on valid model construction and simplification, simulation program verification, complexity reduction, goodness of fit criteria and approximate models, state and parameter identification, structural inference, and model integration.

The interdisciplinary application of theory will concentrate on adaptation and development in natural and artificial systems, with studies of three kinds. Genetic algorithms will be used for optimizing functions, for problems of NP-complexity, and for inductive inference from sparse data. Various cognitive processes will be studied: learning and generalization, pattern recognition, and introspection. Evolutionary processes will be investigated, especially the emergence of self-replicating systems from initially homogeneous media. Some of these studies will be undertaken in coordination with scientists in other disciplines, such as psychology, zoology and oceanography.

Rugers University; Daniel Gorenstein; Finite Group Theory; (MPS 7507512A01); \$15,000; 12 mos. (Joint support with Mathematical Sciences — total grant, \$44,800)

This will provide a second year of support for the research originally provided under MPS 7507512.

Gorenstein plans to carry out research on simple groups of characteristic 2 type in five specific areas: (1) simple groups of 2-local 3-rank at most 1; (2) simple groups with a proper 2-generated p -core or strongly p -embedded subgroup; (3) the existence of general uniqueness theorems for odd primes; (4) simple groups which are balanced for the prime 3, and (5) centralizers of elements of order p , p odd, in standard form.

Sims will continue his work in group theory, particularly in the use of computers to solve group theoretic problems. An effort will be made to generalize the procedures used to construct the Lyons and O'Nan groups. Also, algorithms for working with matrix groups over finite fields will be investigated.

O'Nan will work on three problems: The first problem regards the classification of doubly-transitive groups in which the stabilizer of a point is local. The second problem is an extension of the first. The third problem involves the classification of sporadic groups by centralizers of elements of order three.

Lyons will (1) continue current work on the classification of finite simple groups of 2-1, 3-1 3-rank 1, in which 2-locals are 2-constrained and some 2-local has p -rank at least 3 for some odd p ; (2) attack certain "standard form" centralizer of involution problems relevant to the non 2-constrained case of the 2-local 3-rank 1 problem; (3) investigate possible generalizations of the p -local and 2-local uniqueness theorems of the sort already established in work on (1).

Machine Intelligence in Research

University of California (Los Angeles); Judea Pearl; Investigating Computational Gains from Inexact Processing; (MCS 7518734); \$23,300; 30 mos. (Joint support with Theoretical Computer Science — total grant, \$46,700; 30 mos.)

The ultimate goal of this research is the construction of a computer-based question-answering system which is capable of making useful, though imprecise, inferences about a given data base. Such a system should be able to incorporate approximate statements in its answer vocabulary (e.g., "It probably did rain in Washington on August 1, 1974, but I am only 80% sure"), and draw generalizations on data not contained in the stored data (e.g., "It will probably rain tomorrow, but I am only 80% sure"). While the use of approximate answers to queries about unobserved facts is mandatory, its usage for answering queries about observed facts is prompted by consideration of computational economy. It is intended to cut down the

amount of data admitted into memory, to economize on the amount of data in the easily accessible portion of memory and cut down the amount of search into lower levels (containing finer detail) of memory. The first step in this direction is the development of techniques for quantifying the memory versus error tradeoffs in question-answering systems.

Case Western Reserve University; George W. Ernst; Application of Heuristic Techniques; (MCS 7523412); \$15,900; 24 mos. (Joint support with Software Quality Research Program and Theoretical Computer Science Program — total grant, \$47,800; 24 mos.)

This research is in two areas associated with heuristic methods in Computer problem-solving. The first area will continue to develop a system which verifies Pascal programs (i.e., proves them to be correct). The planned system will be applied to a large number of different kinds of programs. These will fall into two categories:

1. Isolated programs that have different features;
2. A number of program modules that constitute a small portion of a real system.

New theorem-proving methods will be developed and incorporated into the planned system. A special feature of the system is that it uses both resolution and nonresolution theorem-proving in an essential way. In the second area, a program will be implemented that can discover heuristics for certain problem-solving methods. For each method being considered, a formal condition has been derived which characterizes the class of problem for which the method is useful. These formal conditions specify "good" parameters to the methods.

University of Hawaii; David R. Stoutemyer; Scientific Applications of Computer Algebra; (MCS 7522983); \$25,800; 24 mos. (Joint support with Software Quality Research Program — total grant, \$51,600; 24 mos.)

This research is in two areas associated with heuristic methods in Computer problem-mathematical areas of optimization and integral equations. The objective of the planned research is to develop some general-purpose, symbolic packages for use by other researchers to pursue analytic rather than numerical techniques. At the same time, this research should determine whether the present state-of-the-art of symbolic systems is adequate for serious, non-trivial mathematical applications.

University of New Mexico; Nancy Martin; MOLGEN: A Computer Science Application to Molecular Genetics; (MCS 7611935); \$68,000; 24 mos.

The general goal of this research is to develop a computer system (MOLGEN) to assist a molecular geneticist in planning laboratory experiments. The system is to be interactive, drawing on both the expertise of the human geneticist and the expert knowledge stored in the data base. In addition to the knowledge base, the major components of the computer system will be an experimental planning program, an enzyme simulation program, and a DNA structure entry and editing system. Extensive use of heuristic and other "reasoning" strategies at decision points in the programs make this a research project in intelligent systems. Recent growth of technology in molecular genetics has resulted in continuing advances in separative and physical techniques, creating new possibilities for novel combinations of techniques which broaden the horizon of possible experiments. At the same time, it has become increasingly difficult for any one scientist to keep track of what is available, as well as the limitations and uses of the newer techniques. Many "ingenious" discoveries can be viewed as judiciously selected combinations of well established unit processes. Hence an intelligent computer system is likely to be pragmatically useful in this area.

Northwestern University; Lawrence J. Henschen; Automated Theorem Proving; (MCS 7618661); \$49,800; 24 mos. (TQ)

The purpose of this research is to develop the theory and practice necessary to enable computers to perform mathematical deduction using the formalized language of mathematical logic. There are four basic areas:

1. Theorem proving in higher-order logic using both the more usual λ -calculus formulation and also the author's own formulation of higher-order logic using typed first-order logics; the emphasis here will be on understanding the relation between the two systems and extending the results, theoretical and practical, of the first-order methods;
2. Theorem proving methods for Horn sets; the special way in which semantic information can be dealt with for Horn sets will be explored;
3. A new, non-resolution, technique will be explored in which, in the ground case at least, each clause is used exactly once; the method involves the calculation of "covering terms" which tell roughly what possible truth value assignments are still available that could satisfy the set of clauses; and
4. Experiments and comparisons of various theorem-proving methods both as applied specifically to the above problems and as applied to problems in resolution theory in general.

University of Pennsylvania; Ruzena Bajcsy; Identification of Real Outdoor Scenes by a Computer; (MCS 7619465); \$30,000; 24 mos. (Joint support with Engineering Sciences — total grant, \$60,000) (TQ)

This research is concerned with automatic recognition and description of real outdoor scenes having features such as grassy or sandy fields, trees and forests, mountains, snow, rocks, oceans, lakes, or rivers. Low level operators under investigation include saturation, brightness, and texture. With reference to the representation of visual information, the partially ordered structure will receive particular attention. Work will also proceed on the design of a control structure, which is envisioned as an interpreter of procedures in a world model.

This award is a renewal of NSF Grant GJ 43440.

University of Pennsylvania; Aravind Joshi; Research in Natural Language Processing and Mathematical Linguistics; (MCS 7619466); \$100,000; 24 mos. (TQ)

The long-term goal of this research is the development of computer systems which understand and use natural language to perform some "intelligent" tasks; the specific focus is upon the development of formalisms that would be useful as part of a flexible computer system that engages in some form of conversational behavior. The major components of the work are: (1) the development of formalisms for structuring the pattern descriptions (schemata) useful in representing knowledge about linguistic events, recognizing linguistic events, and representing lexical information, (2) the study of the relationship of these formalisms to inferencing, (3) empirical study of language material to aid and support these investigations, (4) development of a computer system incorporating these formalisms, and (5) mathematical investigation of some of these formalisms. This grant is a renewal of research funded under NSF grant SOC 7205465.

University of Rochester; Jerome A. Feldman; Automatic Structure Selection and Related Topics; (MCS 7610825); \$155,900; 24 mos. (TQ)

In this research, techniques from artificial intelligence and theoretical computer science are applied to problems in programming language design and implementation. The central issue is the automatic selection of data structures from higher level specifications. An ancillary research topic is intelligent compilers.

This award is a renewal of DCR 7424203.

University of Southern California; William C. Mann; Dialogue-Based Research in Man/Machine Communication; (MCS 7607332); \$127,100; 12 mos.

Man/machine communication in natural language is the focus of this research. A natural language dialogue model is defined as a process which interrogates and manipulates data structures called "memory states," to understand what aspects of a dialogue are accounted for by such a model, and how they are accounted for, it is imperative that the information content of these states be accessible and interpretable. Text generation is the means used for filling that need. In addition, research on dialogue will extend existing methods to generate coordinated multi-sentence text.

Stanford Research Institute; Ann Robinson and Donald E. Walker; Natural Language Communication with Computers for Task Performance; (MCS 7622004); \$200,000; 12 mos. (TQ)

This research focuses upon communication in natural language between a person and a computer for the accomplishment of a shared task. The goal is to develop general techniques for representing knowledge about tasks and about dialogue structure and for using this knowledge in systems for natural language understanding. The dynamics of processes and events and their relation to dialogue interactions constitute central elements in the effort.

The research addresses a set of key problems that are relevant for a broad range of task domains and that must be solved to provide capabilities for processing task-oriented dialogues. The project efforts will be undertaken and coordinated in the context of a functioning system. The work builds on procedures for natural language processing developed at Stanford Research Institute in research on speech understanding.

Stanford University; E. A. Feigenbaum and Joshua Lederberg; MOLGEN: A Computer Science Application to Molecular Genetics; (MCS 7611649); \$110,700; 24 mos.

The general goal of this research is to develop a computer system (MOLGEN) to assist a molecular geneticist in planning laboratory experiments. The system is to be interactive, drawing on both the expertise of the human geneticist and the expert knowledge stored in the data base. In addition to the knowledge base, the major components of the computer system will be an experimental planning program, an enzyme simulation program, and a DNA structure entry and editing system. Extensive use of heuristic and other "reasoning" strategies at decision points in the programs make this a research project in intelligent systems. Recent growth of technology in molecular genetics has resulted in continuing advances in separative and physical techniques, creating new possibilities for novel combinations of techniques which broaden the horizon of possible experiments. At the same time, it has become increasingly difficult for any one scientist to keep track of what is available, as well as the limitations and uses of the newer techniques. Many "ingenious" discoveries can be viewed as judiciously selected combinations of well established unit processes. Hence an intelligent computer system is likely to be pragmatically useful in this area.

Stanford University; Terry Winograd; Computer Modelling of Language Comprehension Processes; (MCS 7523252); \$101,500; 24 mos.

This research is directed toward the study of the nature of human language understanding, using computer models as a means of formalizing and testing specific theories. Programs will be built which analyze samples of naturally occurring English texts (both narrative and dialogue). These programs will be able to summarize the content of the texts and answer questions about them. The main goal of the research is to develop new formalisms for expressing theories of language and cognition more completely and coherently than currently available formalisms from logic and mathematics. The increase in power will come from dealing explicitly with

notions of *process* and *computation*, using concepts which have been developed in artificial intelligence and other areas of computer science. Since the research includes writing working computer programs, there will be operational criteria for testing the validity and generality of the theories.

University of Texas (Austin); Woodrow W. Bledsoe; Research in Automatic Theorem Proving; (MCS 7412866A02); \$41,100; 12 mos. (TQ)

The research is a continuation of work in automatic theorem proving. The effort has included heuristically directed programs, results in non-standard analysis, and man/machine provers applied to analysis and program verification. The proposed investigation will continue this research including the construction of a new prover.

This is the third year of a continuing grant.

University of Utah; R. E. Barnhill and R. F. Riesenfeld; Computer Aided Geometric Design; (MCS 7413017A01); \$167,900; 24 mos.

This project, which continues research initiated under DCR-7413017, concerns the mathematical description and computer implementation of methods for representing free-form curved surfaces. Past efforts in this field have not provided adequate answers because they have failed to take into account a sufficient number of requirements. Some mathematical procedures are capable of describing broad classes of shapes, but the apparent difficulty in casting their controlling parameters in a form suitable for human manipulation via available input devices has rendered them unsuitable for use in an interactive design system. This project entails both the development of new bivariate interpolation schemes that are smooth and involve accessible design parameters, and the implementation of these schemes as well as of schemes that are already known. This research has many applications, including the design of aircraft, automobiles, and ships, and modelling of the surface of the human heart.

University of Wisconsin (Madison); Leonard Uhr; Computer-Programmed Models of Wholistic Integrated Cognitive Systems; (MCS 7607333); \$33,500; 24 mos. (Joint support with Theoretical Computer Science — total grant, \$67,500; 24 mos.)

This project involves research for developing a computer-programmed model of the mind/brain where the various cognitive processes are integrated into a single wholistic system. The long-term goal is to achieve a system that can learn to perform the variety of cognitive tasks handled by an ordinary human being. This means that the single system must be able to effect a wide range of processes, to recognize patterns, describe scenes, form concepts, solve simple problems, understand language, access and converse about remembered information, act upon and manipulate its environment, and learn.

Studies and Colloquia

National Academy of Sciences; William Spindel; Support of a Symposium on Interaction of Recent Developments in Computer Science with Crystallography, January 23, 1976; (MCS 7606183); \$3,700; 12 mos.

This project is a one-day symposium on the interaction of recent developments in computer science with experimental physical sciences, in particular, crystallography.

Topics to be included in the symposium are:

1. The formulation and stimulation of new algorithms to increase computational efficiency;

2. Artificial intelligence (i.e., nonnumerical methods) for the solution of experimental problems;
3. Interactive computing as an adjunct to experimental measurement;
4. The impact of rapid developments in computational hardware (e.g., mini- and microcomputers) on experimental work in crystallography and other fields, and an examination of the best way to bring these developments into widespread and efficient use.

University of Pittsburgh; Siegfried Treu; User-Oriented Design of Interactive Graphics Systems: A Structured Workshop, Pittsburgh, Pennsylvania, October 14-15, 1976; (MCS 7616603); \$4,400; 12 mos.

An ACM/SIGGRAPH-sponsored workshop on User-Oriented Design of Interactive Graphics Systems is planned for October 14-15, 1976 in Pittsburgh, Pa. It will focus on behavioral characteristics involved and on cognitive and conceptual processes required in user interaction with graphics systems for various applications, and will consider the implications of these on graphics system design.

The workshop is to be highly structured. Cross-disciplinary and cross-societal participation is encouraged. Some special guest speakers will be invited. Both technical and position papers are being solicited, but not for formal presentation at the workshop. If accepted by the program committee, they will be distributed to the attendees in preparation for the workshop, and will then be published in the formal workshop proceedings.

NETWORKING FOR SCIENCE

EDUCOM Inc.; James C. Emery; Simulation and Gaming Project for Inter-Institutional Computer Networking; (MCS 7503634A01); \$153,000; 12 mos. (Joint support with Division of Science Information - total grant, \$293,800; 12 mos.)

The project is a collaborative effort on the part of 16 institutions in cooperation with EDUCOM to construct a computer simulation model directed principally at questions of institutional impacts of computer networking for computing and information services on a national basis in support of science research and education. The model, in turn, will become the basis for a more comprehensive investigation into the organizational impacts of a network, the conditions necessary for a successful network and the likely problem areas that must be monitored.

The previous award number is DCR 7503634.

Illinois Institute of Technology; Peter H. Greene; Distributed Task Organization for Computer Networks; (MCS 7601310); \$110,600; 24 mos. (Joint support with Techniques and Systems — total grant, \$190,600; 24 mos.)

This research is directed toward extending the range of utilization of networks of very small computers. The work to be done includes studies in the requisite mathematical theory, the generation of programming techniques for loosely-coupled procedures distributed over a network and for their parallel operation, as well as tests of the resulting methods in a microcomputer network.

The results of this work should provide a base on which to enlarge the intelligent systems type of microcomputer utilization.

Massachusetts Institute of Technology; Michael Athans and Robert Gallager; The Dynamics of Data Networks; (ENG 7514103); \$15,000; 12 mos. (Joint support with Engineering Sciences — total grant, \$75,000; 12 mos.)

This research program is aimed at developing fundamental understanding of the dynamic behavior of data communication networks. The two principal objectives of this work are the development of:

1. Theory of protocols required in a network for such purposes as identifying messages and their destination, for controlling errors and for enabling recovery from node and link malfunctions;
2. Theory of network control aimed at utilizing the protocol information in routing and recovery algorithms.

The approach will utilize techniques from communications, control and stochastic processes.

Massachusetts Institute of Technology; Michael Athans and Robert Gallager; The Dynamics of Data Networks; (ENG 7624447); \$17,300; 12 mos. (Joint support with Engineering Sciences — total grant, \$92,300) (TQ)

This research program is aimed at developing fundamental understanding of the dynamic behavior of data communication networks. Specifically, further work on the following problem areas will be pursued:

1. Protocol Information in Data Networks;

2. Routing Algorithms and Associated Control Problems.

New important problems that will be addressed include congestion control network design with limited state information at the nodes of the network, and link and node failures.

This award renews the research supported under NSF Grant ENG 7514103.

University of Minnesota (Minneapolis); G. Michael Schneider; Design of a Data Specification and Conversion Language for Networks; (MCS 7509789); \$34,300; 24 mos.

This project is focused on producing software necessary for transcending physical, logical, and organizational incompatibilities in information within heterogeneous computer networks. The instrument for rendering these incompatibilities transparent is a processor, of which one major component is a Data Specification and Conversion Language (DSCL).

The computer network resource-sharing which would be thus facilitated includes programs, data, and hardware devices, as well as "remote bootstrapping." The goal is thereby to improve user-oriented service on networks.

NERComP, Inc.; Robert A. Rolla; Research and Exploration of Governance, Facilitating, and Operating Network Structures; (DCR 7403791A01); \$84,900; 12 mos.

This is the second year of a project for which the purpose is to conduct research and experimentation into governance and facilitating methods that will promote a general purpose network for computer services for research and education. The New England Regional Computing Program (NERComP) involving over forty colleges and universities will provide the institutional base for the conduct of this project. The principal emphasis will be on exploring and evaluating organizational considerations underlying this mode of resource-sharing.

Stanford University; Donald A. Dunn; Economics of Computer Communication Networks; (MCS 7605326); \$131,500; 12 mos. (Joint support with Science Information Service - total grant, \$181,500; 12 mos.)

The project is a long-term research program in the economics of computer communication networks. An analysis will be done of systems technology and cost, services, demand for services, patterns of industrial response to demand and societal effects of the provision of services. The analytical topics form a three-dimensional matrix of levels of analyses, classes of services and classes of networks.

SOFTWARE QUALITY RESEARCH

Argonne National Laboratory; W. R. Cowell; The LINPACK Project: Collaborative Research on Quality Software for Linear Systems; (MCS 7603296); \$91,100; 12 mos.

This is part of a collaborative research effort to create high-quality, mathematical software for the solution of linear systems. The project is intended to serve as a model for future projects of this kind. The project is to be carried out jointly by investigators at several universities and by the Applied Mathematics Division of Argonne National Laboratory.

The functions to be carried out by researchers at Argonne National Laboratory include the systematization of the software modules, validation through coordination with field test sites, evaluation and documentation of the software engineering aspects, generation of test data, measurement of software performance, and the possible adaptation of the software to virtual or paged memory systems.

Argonne National Laboratory; Wayne R. Cowell; Workshop on Portability of Numerical Software, Oakbrook, Illinois, June 21, 1976 - June 24, 1976; (MCS 7616584); \$9,400; 6 mos.

This workshop focuses on software techniques for transporting mathematical software between different computer systems. The purpose is to bring together researchers who have now acquired experience with first generation portability systems and to evaluate the approaches used, the outstanding issues, and the goals for future work. The date of the workshop is June 21-24, 1976.

University of Arizona; David G. Ripley and Ralph E. Griswold; The Measurement of High-Level Programming Languages; (MCS 7521757); \$43,900; 24 mos.

This research is concerned with the measurement and analysis of computer programs written in high-level programming languages. The research is directed toward the identification and development of measurement facilities which can be related to the source language level. Also, concepts from relational data bases are to be used in developing a data model for measurement. Execution-time analysis is to be treated as an extension of the work in program measurement.

University of California (San Diego); James R. Bunch; The LINPACK Project: Collaborative Research on Quality Software for Linear Systems; (MCS 7603139); \$57,900; 30 mos.

This is part of a collaborative research effort to create high-quality, mathematical software for the solution of linear systems. The project is intended to serve as a model for future projects of this kind. The project is to be carried out jointly by investigators at several universities and by the Applied Mathematics Division of Argonne National Laboratory.

This research is concerned with determining the relative merits of various algorithms for solving special systems of equations and determining appropriate data structures for handling symmetric, banded, and sparse matrices. The special systems include symmetric, (Hermitian) indefinite systems, general, real and complex, banded systems; and real, symmetric, positive definite, banded systems.

University of California (San Diego); Edward H. Coughran; Operational Test of the LINPACK Project: Validation of Mathematical Software for Linear Systems; (MCS 7601739); \$7,900; 30 mos.

This project is directed toward testing the mathematical software for solutions of various types of linear systems that emerge from the research of the LINPACK project. As an independent test site, it will be concerned with measuring the quality of the software, its transportability, accuracy, robustness, efficiency, documentation, and completeness.

University of California (San Diego); William D. Howden; Reliability of Strategies for Testing Computer Programs; (MCS 7603295); \$50,000; 24 mos.

The purpose of this research is to investigate the reliability of the various strategies that are used for testing computer programs. This includes the investigation of different path-testing strategies, a characterization of the strategies as to their reliability, and a generalization of these ideas to broader classes of programs using program models.

Case Western Reserve University; George W. Ernst; Application of Heuristic Techniques; (MCS 7523412); \$15,900; 24 mos. (Joint support with Theoretical Computer Science and Techniques and Systems Programs - total grant, \$47,800; 24 mos.)

This research is in two areas associated with heuristic methods in Computer problem-solving. The first area will continue to develop a system which verifies Pascal programs i.e., proves them to be correct). This system will be applied to a large number of different kinds of programs. These fall into two categories:

1. Isolated programs that have different features;
2. A number of program modules that constitute a small portion of a real system.

New theorem proving methods will be developed and incorporated into the system. A special feature of the system is that it uses both resolution and nonresolution theorem proving in an essential way. In the second area, a program that can discover heuristics for certain problem-solving methods will be implemented. For each method concerned, a formal condition has been derived which characterizes the class of problems for which the method is useful. The formal conditions specify "good" parameters to the methods.

Colorado State University; Michael Andrews; Efficient Software for Elementary Functions Evaluation on Microprocessors; (MCS 7612457); \$60,000; 24 mos. (TQ)

This research is concerned with algorithms and software for elementary functions on microprocessors. The problems to be investigated include guidelines for choosing algorithms, identifying optimal coefficients for approximants, and determining the advantages of combining coarse table look-up and iterative techniques with best uniform approximants. An evaluation of the algorithms and their performance on specific microprocessors will be included as part of this research effort.

University of Colorado; Lloyd D. Fosdick and Leon J. Osterweil; Analysis of Mathematical Software for the Purpose of Validation and Documentation; (MCS 7509972A01); \$165,900; 12 mos.

The purpose of this research is to investigate software validation techniques based upon the previous research of the Principal Investigators. This has included evaluation and testing of the

DAVE system for the validation of software, formalizing the underlying data flow analysis principles upon which the DAVE system is based, and transporting the system to other computer systems.

Continued research efforts will explore a variety of approaches to data flow analysis, such as the automatic generation of test data and detection of certain unexecutable paths.

University of Colorado; Linda Kaufman; Research in Using Matrix Decomposition in Function Minimization and Eigenvalue Problems; (MCS 7523333); \$14,800; 24 mos. (Joint support with Theoretical Computer Science Program - total grant, \$29,600; 24 mos.)

In recent years techniques have been developed for the creation and the updating of various matrix decompositions such as the singular value decomposition, the orthogonal decomposition and the decomposition of symmetric matrix. The purpose of this research is to apply these techniques to minimization problems and certain eigenvalue problems. Emphasis will be on algorithm development and implementation.

University of Connecticut; John R. White; An Incremental Approach to Reliable Programming Language Translators; (MCS 7500325); \$45,500; 24 mos.

This research is concerned with the process of designing reliable programming language translators and focuses on the problems of complexity in semantic phase of the translation process. A technique is proposed based upon the concepts of structured programming, a formalized set of linguistic constructs, compile-time abstractions, and run-time abstractions. The purpose of the compile-time abstractions is to simplify the implementation of the mapping from the source language L into the object language L'; the purpose of the run-time abstractions is to simplify the mapping itself. The proposed research addresses a fundamental problem associated with the semantic phase of the translator writing systems (TWS). The approach to code generation, the use of abstraction, and the incremental top-down approach are promising avenues of research.

Harvard University; Garrett Birkhoff and Donald G. M. Anderson; Evaluative Analysis of Algorithms for Scientific and Engineering Computing; (MCS 7307984A02); \$19,500; 12 mos. (Joint support with Engineering Sciences - total grant, \$37,500; 12 mos.)

The emphasis of this research is on evaluating collections of algorithms that are basic to many scientific and engineering problems. Specific areas of study are:

1. Linear systems of equations, including direct methods for dense matrices, iterative methods for large sparse matrices, and direct methods for large sparse matrices with special structure;
2. Two-point boundary value problems, including multiple or parallel shooting methods; and
3. Nonlinear optimization.

University of Hawaii; David R. Stoutemyer; Scientific Applications of Computer Algebra; (MCS 7522983); \$25,800; 24 mos. (Joint support with Techniques & Systems Program - total grant, \$51,600; 24 mos.)

This research project is concerned with the application of existing symbolic systems to the mathematical areas of optimization and integral equations. The objective of the proposed research is to develop some general-purpose, symbolic packages for use by other researchers to

pursue analytic rather than numerical techniques. At the same time, this research should determine whether the present state-of-the-art of symbolic systems is adequate for serious, nontrivial mathematical applications.

University of Illinois (Chicago Circle); Ronald William Golland and Thomas H. Brown; Operational Test of the LINPACK Project: Validation of Mathematical Software for Linear Systems; (MCS 7607073); \$7,500; 30 mos.

This project is directed toward testing the mathematical software for solutions of various types of linear systems that emerge from the research of the LINPACK project. As an independent test site, it will be concerned with measuring the quality of the software, its transportability, accuracy, robustness, efficiency, documentation, and completeness.

University of Illinois (Urbana); Mary Ann Berg and Dillon E. Mapother; Operational Test of the LINPACK Project: Validation of Mathematical Software for Linear Systems; (MCS 7602356); \$7,500; 30 mos.

This project is directed toward testing the mathematical software for solutions of various types of linear systems that emerge from the research of the LINPACK project. As an independent test site, it will be concerned with measuring the quality of the software, its transportability, accuracy, robustness, efficiency, documentation, and completeness.

University of Illinois (Urbana); David J. Kuck and Ahmed Sameh; High Quality Software for Numerical Computations; (MCS 7521758); \$23,300; 24 mos. (Joint support with Theoretical Computer Science Program - total grant, \$46,600; 24 mos.)

This research is concerned with the problem of how to create high-quality software for future multioperation computers. The objective is to be able to compile a numerically stable algorithm for a multioperation machine from a numerically stable sequential algorithm, when possible, through the mechanism of properly parsing the algorithm. The class of algorithms to be studied is limited to those of linear algebra, but the research applies to the larger problems of high-quality compilers and languages for multioperation computers.

International Mathematical & Statistical Libraries, Inc.; Edward L. Battiste; Portability of Mathematical and Statistical Software Coded in American National Standards Institute (ANSI) FORTRAN; (MCS 7522349); \$38,500; 6 mos.

This is a continuation of a study begun under a previous NSF grant and is concerned with the portability of mathematical software for all common, domestic, large-scale computers. In particular, the current study intends to extend the results of the previous study to other large-scale computers that were not included in the original grant. Central to the concept is a converter which automatically "converts" specialized code from one computer to another. The object is to make specific types of software libraries portable. The converter and the concept will be tested on prototype libraries. The results will be made available to the scientific community.

University of Iowa; Kendall Atkinson; Numerical Solution of Integral Equations; (MCS 7606094); \$17,900; 24 mos. (Joint support with Theoretical Computer Science Program - total grant \$35,800; 24 mos.)

This project is concerned with the numerical solution of Fredholm linear integral equations of the second kind. The integral equation problems to be considered are as follows: (1) extension of previous work to the case in which the solution function has singularities in some low order derivative; (2) systems of integral equations; (3) integral equations with a singular kernel function; (4) multidimensional integral equations; and (5) the eigenvalue problem for integral operators, especially the case of a real, symmetric kernel function which is several times continuously differentiable. The main numerical techniques to be used are variations of the Nystrom method, with both direct and iterative methods of solution for the resulting linear system.

University of Maryland (College Park); Azriel Rosenfeld; A Study of Specifications and Criteria for the Standardization, Certification and Dissemination of Image Processing Software; (MCS 7602156); \$19,500; 12 mos.

This is a collaborative study and is aimed at establishing specifications and criteria for the standardization, certification, and distribution of image processing software. Special emphasis will be placed on the portability aspects of image processing software that are unique or different from other types of software. The study will culminate with a formal report.

University of Maryland (College Park); G. W. Stewart; The LINPACK Project: Collaborative Research on Quality Software for Linear Systems; (MCS 7603297); \$57,700; 30 mos.)

This is part of a collaborative research effort to create high-quality, mathematical software for the solution of linear systems. The project is intended to serve as a model for future projects of this kind. The project is to be carried out jointly by investigators at several universities and by the Applied Mathematics Division of Argonne National Laboratory.

The specific research to be pursued in this part of the LINPACK project includes the creation of high-quality software for the QR decomposition and the singular value. In addition, further research on the problems associated with out-of-core decomposition of dense linear systems will be studied with possible applications to minicomputers.

University of Maryland (College Park); John D. Gannon; Data Types and Programming Reliability; (MCS 7623346); \$25,800; 12 mos. (TQ)

The goals of this research are to discover language features which enhance programming reliability and to develop a methodology for validating that the language features achieve the desired result. The language features under consideration are those which contribute to the data type feature in programming languages. The method for evaluating these features will be an experiment involving subjects solving programming tasks both in a statically typed language and a "typeless" language. Results from this experiment should help advance programming language design toward a human engineering discipline.

Massachusetts Institute of Technology; Roy E. Welsch; Computer Science and Statistics: Ninth Annual Symposium on the Interface, April 1, 2, 1976; (MCS 7607331); \$7,500; 12 mos.

The "Computer Science and Statistics: Ninth Annual Symposium on the Interface" is composed of six workshops: graphics, numerical analysis, statistical package evaluation, robust

software, high-level languages and statistics, and minicomputers and statistics. Position papers for each workshop are intended to focus attention upon the problems and possible solutions of the interface between the two disciplines. A Proceedings of the symposium will be published after the meeting.

University of Michigan (Ann Arbor); Matthew Geller; Test Data as an Aid in Proving Program Correctness; (MCS 7607744); \$39,400; 24 mos. (TQ)

This project will examine ways in which test data can be used to prove program correctness. The effectiveness of using test data values in specifying program behavior and the role of test data in simplifying verification techniques will be examined. Methods will be developed for generalizing from test data values to behavior of program variables for any input in the input domain.

The problem of applying the techniques to different types of programs will be examined and made applicable to large programs. The techniques will also be applied to programs that use various data structures. The problem of using test data to check halting of a program will also be considered.

National Bureau of Economic Research, Inc.; John Dennis and David M. Gay; Effective Modularization of Nonlinear Unconstrained Optimization Subroutines: A Substantive User Liaison with MINPACK; (MCS 7600324); \$61,700; 12 mos.

This research is a collaborative effort between Cornell University and the NBER Computer Research Center and is directed toward understanding the quality of the software that is associated with nonlinear unconstrained optimization. An important aspect of the research is the construction of a suitable set of application problems for testing the MINPACK software package. The work will be coordinated with MINPACK group at Argonne National Laboratory. The intent of this collaborative research is to provide an in-depth analysis of the algorithms, to determine the quality of the software, and to test the suitability of the software for several application areas.

National Bureau of Economic Research, Inc.; Gene H. Golub and Virginia Klema; Numerical Computation of Robust and Nonlinear Statistical Estimators; (MCS 7611989); \$117,500; 24 mos.

This research is interdisciplinary in nature and involves collaborative research efforts in the areas of quality software, statistics, and numerical analysis. The work will focus on high-quality software and associated algorithms for nonlinear statistical estimation methods. These methods and the corresponding software are to form a basic set of modules which can be used in the conduct of scientific research in application areas, such as economics and energy modeling.

University of New Mexico; Herbert T. Davis; Time Series Packages - Evaluation of Statistical Software; (MCS 7606477); \$10,800; 12 mos.

This research is concerned with the evaluation of software packages for time series. The work is to be considered as an independent effort to analyze the characteristics and documentation of existing packages, but its results are to be integrated into the larger effort that is being conducted by the American Statistical Association's Committee on the Evaluation of Statistical Packages.

University of New Mexico; C. B. Moler; The LINPACK Project; Collaborative Research on Quality Software for Linear Systems; (MCS 7603052); \$57,500; 30 mos.

This is part of a collaborative research effort to create high-quality, mathematical software for the solution of linear systems. The project is intended to serve as a model for future projects of this kind. The project is to be carried out jointly by investigators at several universities and by the Applied Mathematics Division of Argonne National Laboratory.

This research is composed of three parts. First, there is the implementation, documentation, and testing of software for the general nonsymmetric matrices and positive definite symmetric matrices. Second, there is the development of techniques that will be useful for future releases of LINPACK. Third, there is the application of LINPACK and EISPACK to scientific and engineering problems.

Northwestern University; Benjamin Mittman; Operational Test of the LINPACK Project: Validation of Mathematical Software for Linear Systems; (MCS 7603140); \$7,500; 30 mos.)

This project is directed toward testing the mathematical software for solutions of various types of linear systems that emerge from the research of the LINPACK project. As an independent test site, it will be concerned with measuring the quality of the software, its transportability, accuracy, robustness, efficiency, documentation, and completeness.

Pennsylvania State University; Webb C. Miller; Software for Roundoff Analysis; (MCS 7613561); \$13,000; 3 mos.

Automatic roundoff analysis has concentrated on identifying the ideas and producing the software to analyze direct methods of numerical linear algebra. The objective of this research is to continue this research and to extend the ideas and software to cover methods in closely related areas, such as iterative matrix methods, algorithms for linear programming, and matrix methods for parallel computers.

Pennsylvania State University; Webb C. Miller; Software for Roundoff Analysis; (MCS 7613561A01); \$38,300; 21 mos. (TQ)

This is a continuation of work started under grant MCS 7613561.

Purdue University; John R. Rice; A Comparative Evaluation of Techniques for Partial Differential Equations; (MCS 7610225); \$91,000; 24 mos. (TQ)

This research is concerned with the analysis and evaluation of computational methods for elliptic partial differential equations, including detailed comparisons of standard finite differences, collocation, Galerkin, and least squares, as well as certain engineering packages, fast methods (FFT), and new methods based on higher order differences. A second aspect will be concerned with the design of software system for elliptic partial differential equations.

Rensselaer Polytechnic Institute; Herbert Freeman; Study of Specifications and Criteria for the Standardization, Certification and Dissemination of Image Processing Software; (MCS 7602661); \$11,300; 12 mos.

This is a collaborative study and is aimed at establishing specifications and criteria for the standardization, certification, and distribution of image processing software. Special emphasis will be placed on the portability aspects of image processing software that are unique or different from other types of software. The study will culminate with a formal report.

Texas A & M University; Oliver Aberth; Precise Computation Routines; (MCS 7606091); \$26,700; 24 mos. (TQ)

This is continuation of the research work done under grant GJ36879.

This project is concerned with extending previous work on software for precise computation. A new method of exact computation with rational numbers will be investigated and tested. It is applicable to problems in the rational number field where the rational form P/Q of the result is desired rather than an approximation to it.

University of Texas (Austin); Dale G. Bettis and David G. Hull; High Order Runge-Kutta Methods; (MCS 7517309); \$16,900; 12 mos. (Joint support with Theoretical Computer Science Program - total grant, \$33,800; 12 mos.)

The purpose of this study is to develop efficient high-order explicit Runge-Kutta methods for solving the initial value problem for systems of ordinary differential equations. An efficient method yields a solution of a specified accuracy with a minimum cost. Cost is measured as the total computing time and/or the total number of function evaluations. Recent test results comparing multi-step, extrapolation, and Runge-Kutta methods show that the Runge-Kutta methods are very competitive with the other methods, particularly when the function evaluations are not expensive.

The methods to be developed will have an accurate estimate of the local truncation error term, thereby allowing the implementation of a variable-step (and, possibly, a variable-order) strategy. The coefficients of the Runge-Kutta method will be selected so that the local truncation error is minimized and that the stability region is maximized. Also, the coefficients will be chosen so that a quadrature problem can be solved by the method and that, in this case, the local truncation error estimate is reliable.

The new Runge-Kutta methods are to be developed for systems of first-order differential equations. The feasibility of extending the techniques to the generation of methods for systems of second-order (and higher) ordinary differential equations will be considered.

University of Texas (Austin); Dale G. Bettis and J. Tinsley Oden; Runge-Kutta and Runge-Kutta-Nystrom Formulas and Software; (MCS 7620022); \$20,600; 24 mos. (Joint support with Theoretical Computer Science - total grant, \$61,800; 24 mos.) (TQ)

Embedded pairs of explicit Runge-Kutta and Runge-Kutta-Nystrom methods will be developed for systems of first- and of second-order ordinary differential equations. These methods have an accurate estimate of the local truncation error, allowing the implementation of a variable-step and a variable-order strategy. Coefficients are selected so that the local truncation error is minimized and that the stability region is maximized. Also, coefficients for lower-order methods of the pair are obtained. Methods will be developed for the special case in which the first m total derivatives are known.

University of Texas (Austin); Alan K. Cline; Evaluation and Analysis of Software for Statistical Regression; (MCS 7607072); \$36,000; 24 mos.

This research is concerned with high-quality software for statistical regression computations. This includes testing, certification, and documentation of the modules which form the basis for the regression software. Step-wise regression and provision for large models which cannot be core contained are to be included as part of the overall software capability.

University of Texas (Austin); James W. Daniel; Accelerating Convergence of Collocation Methods; (MCS 7622015); \$24,400; 24 mos. (TQ)

This research project is to investigate the approximate numerical solution of general nonlinear two-point boundary-value problems by using deferred corrections or Richardson extrapolation to accelerate the convergence of approximations generated by collocation methods using spline functions; research-oriented computer codes will be developed for some such methods and these implementations will be compared to determine which methods should be developed more fully as the potential basis for high-quality software.

University of Texas (Austin); David M. Young and David R. Kincaid; A Comparative Study of Iterative Algorithms for Elliptic Partial Differential Equations Software; (MCS 7603140); \$28,000; 12 mos.

This is an exploratory study of various iterative algorithms that are candidates for a mathematical software package for the solution of a broad class of elliptic partial differential equations. The study will include both finite difference and finite element methods. Adaptive procedures will be used for the automatic determination of iterative parameters that are used in the algorithms. Special attention will also be given to the question of when to terminate the iterative process.

In addition to the exploratory study, there also will be active collaboration with researchers at Harvard University and Purdue University. The study will culminate with a workshop which will produce a report with recommendations for future directions for the mathematical software community.

University of Utah; Anthony C. Hearn and Martin L. Griss; Improved Software for Symbolic and Algebraic Manipulation; (MCS 7615053); \$149,400; 24 mos.

This research is devoted to the continuing development of improved software for the solution of symbolic and algebraic problems in areas of science and engineering. It is oriented towards both algorithm and system development and the use of the results in solving practical problems. Particular emphasis is placed on developing methods for making such programs easy to use and widely available.

College of William and Mary; William G. Poole; Operational Test of the LINPACK Project: Validation of Mathematical Software for Linear Systems; (MCS 7608946); \$8,000; 30 mos.

This project is directed toward testing the mathematical software for solutions of various types of linear systems that emerge from the research of the LINPACK project. As an independent test site, it will be concerned with measuring the quality of the software, its transportability, accuracy, robustness, efficiency, documentation, and completeness.

University of Wisconsin (Madison); Larry E. Travis; Operational Test of the LINPACK Project: Validation of Mathematical Software for Linear Systems; (MCS 7604069); \$7,500; 30 mos.

This project is directed toward testing the mathematical software for solutions of various types of linear systems that emerge from the research of the LINPACK project. As an independent test site, it will be concerned with measuring the quality of the software, its transportability, accuracy, robustness, efficiency, documentation, and completeness.

SPECIAL PROJECTS

Modeling

University of Houston; Olin Johnson; Interactive Graphics Methodologies for Energy Models and Energy Model Development Systems; (MCS 7417282); \$79,100; 12 mos.

Research into graphics methodologies for model development systems will utilize the NBER TROLL system. The methodologies to be investigated fall into three classes: (1) computational, (2) perturbational, and (3) informational. Computational methods for solving graphics energy models will be investigated for speed of solution, speed of sub-computations, minimization of re-computation due to parameter variations and adaptability to interactive graphics requirements.

Perturbational methods, including interval analysis, ellipsoidal analysis and stochastic analysis will be investigated to determine how graphics components can best be imbedded and utilized.

Informational methods of graphics display such as positioning, scaling, graphic potentiometers, and pointing, will be tried in concert with computational and perturbational methodologies in order to determine and thus optimize the understandability and usability of the combined techniques by semi-technical personnel and by policy makers.

University of Missouri (Rolla); John R. Metzner; Use of Macroprogramming Systems for Large-Scale Computer Based Models; (MCS 7515839); \$39,700; 24 mos.

The two-year research project will investigate the possibility of applying generalized macroprogramming techniques to discrete-event digital simulation programming for the purpose of improving both the efficiency of the simulation programming process and the clarity of the programs produced. The predominant pattern of the research will be the generalization of macroprogramming concepts and techniques, their application to simulation programming, and the evaluation of their productiveness in the resulting program production systems. Major enhancement candidates are facilities analogous to those of conditional assembly and decision table translation. Adding such features to an event-oriented simulation programming language will yield not just a higher-level programming language but a program production system capable of generating simulation programs from input that is much more concise and descriptive of the model it embodies than the simulation program can be.

National Bureau of Economic Research, Inc.; Roy E. Marsten; XMP: A Structured System of Subroutines for Mathematical Programming; (MCS 7601311); \$99,600; 12 mos.

Research will be conducted on the Mathematical Programming component of optimizing models. The primary emphasis will be on investigating the model-specification, data-manipulation and result-reporting subsystems. The research will be conducted in the context of XMP, a highly modular computer program system designed for research in mathematical programming and econometric research, and will take place in the large-scale energy modeling environment at the NBER Computer Research Center at Cambridge.

National Bureau of Economic Research, Inc.; John R. Meyer and Edwin Kuh; Research on the Energy-Modeling Process; (MCS 7510143A01); \$100,000; 0 mos. (Joint support with Social Sciences - total grant, \$150,000)

The NBER Computer Research Center will pursue research on an experimental system-support environment for the three principal phases of energy-modeling work—algorithm development, model building, and policy analysis. The system-support requirements of each phase will be analyzed, and functional elements responsive to those requirements will be implemented in an integrated experimental environment. Preliminary work will also be performed on sophisticated numerical, statistical, and Monte Carlo techniques for testing and evaluating algorithms and models. The experimental environment will be tested, evaluated, and refined through production use by algorithm developers and model builders, and government policy analysts.

National Bureau of Economic Research, Inc.; Jeremy F. Shapiro; Dual Methods for Mixed Integer Programming: Sensitivity Analysis, Multicriterion Optimization and Decomposition; (MCS 7520988); \$25,000; 24 mos. (Joint support with Theoretical Computer Science - total grant, \$77,300; 24 mos.)

A complete duality theory for mixed integer programming has recently been developed. The theory involves the construction of a finite sequence of increasingly strong dual problems; the last dual problem in the sequence provides an optimal solution to the mixed integer programming problem. The duals are non-differentiable concave maximization problems. The research will focus on the numerical and computational aspects of constructing and solving the dual problems. Their use in conjunction with branch and bound will also be studied further. Extensions of the dual methods will be condensed to sensitivity analysis, multicriterion optimization and decomposition of mixed integer programming problems.

RAND Corporation; Mario L. Juncosa; Three-Dimensional Modeling: Partial Differential Equations; (MCS 7423901A02); \$50,700; 12 mos.

This project will compile information on formulations, computer usage and requirements, software efforts, and experience gained in the numerical solution of a variety of three-space dimensional modeling or simulation problems involving partial differential equations with and without time dependence. A large fraction of the three-dimensional simulations relate to problems in atmospheric and ocean sciences and influences on the environment (climate, estuarial flows, pollution). Also of interest will be high-speed hydrodynamic codes and other physical models with particular energy relatedness.

Typical information sought will be physico-mathematical items such as descriptions of the models, mathematical formulations and methods employed for solution, and computational items such as size of problem solved, computer used and the extent of its characteristics employed, running times, programming efforts and other costs, and flexibility of resulting code. Wherever possible, important by-product information on mathematical or computational limitations on current modeling, pointing at key items for future research and development, will also be sought.

Previous award # DCR-7423901.

University of Southern California; Richard E. Bellman; Invariant Imbedding in Engineering, Physiology, and Applied Sciences; (MCS 7423539A01); \$32,800; 12 mos.

The principal purpose of this research is to develop, analyze, and do a computational study of the concepts and algorithms of invariant imbedding and dynamic programming for solving complicated practical problems in engineering and energy systems. Emphasis is placed on both

computational aspects and new invariant imbedding formulations which are especially suited for solving complicated boundary value problems. The goals of this research are to develop and to increase the calculational effectiveness of invariant imbedding and to formulate computational procedures for complicated boundary value problems whose solutions cannot be obtained easily by traditional numerical techniques.

The fundamental problems in the development of three energy sources are being studied by the use of invariant imbedding: (1) coal combustion and gasification, (2) the modeling of geothermal energy, and (3) solar energy developments.

University of Washington; M. J. Damborg; Dynamic Model Validation and Evaluation; (MCS 7516542); \$30,600; 12 mos.

This project will study algorithms for model validation and evaluation and implement these algorithms in a software package. The project will consider nonlinear difference equation models, the type commonly used in large-scale problems such as energy systems and econometric studies, and will study error propagation criteria as determined by time series analysis.

Washington University; Mark A. Franklin; Continuous Systems Simulation on Multiprocessor Systems; (MCS 7518735); \$50,500; 12 mos.

This project is concerned with continuous system simulation, and, if successful, may increase substantially the speed and lower the cost of performing continuous system simulation on digital computers. The emphasis of this research is twofold. First, it will explore the design of model solution algorithms which are parallel, rather than serial in nature. Such parallel algorithms may be implemented on multiprocessor computer systems, thus enhancing the speed of executing simulation models. Second, it will investigate the design of appropriate multiprocessor computer systems which can be built using currently available mini- and microprocessor hardware.

Privacy and Security

University of California (Berkeley); Robert S. Fabry; Capability-Based Protection of Computer Data Systems; (MCS 7523739); \$47,900; 24 mos.

This research project will explore developing practical schemes for implementing fine-grained computer protection. Research will be based on a process model which distinguishes information used by all invocations of a subsystem, information used by all invocations within a process, and information private to each invocation. Problems to be attacked include inter-subsystem references, revocation and propagation of capabilities, and condition handling.

University of California (Berkeley); Lance J. Hoffman; Models and Metrics for Secure Computer Systems; (MCS 7609214); \$38,300; 12 mos.

The project will develop and study a formal model which focuses upon the interactions of the security measures in a computing system with the threats they combat and with the objects they protect. The concept of "resistance" (security measure effectiveness) will be combined with some measure of threat probability and object value at each interaction point in the system to arrive at that measure's contribution to overall system security. The model will systematize the resistance, probability, and value measurement process. The problem of imprecision in these measurements will be examined.

In addition, the establishment of a small software cryptographic laboratory is planned. The computer programs available here will aid in the development of computer-assisted statistical

analysis techniques for cryptography, pattern recognition techniques in cryptanalysis, and a computational-complexity oriented study of new and promising encryption techniques such as the proposed Federal standard.

Carnegie-Mellon University; A. K. Jones; Research on the Security of Computation; (MCS 7606344); \$22,600; 12 mos.

The principal investigator will collaborate with Professor Richard Lipton at Yale University in research aimed at developing a formalization of the concept of controlled dissemination of information from computer data bases. Their goal is to develop a formal theory that integrates understanding of security policies and protection mechanisms.

Purdue University; Peter J. Denning; Computer Architecture for Security and Reliability; (MCS 7521100); \$17,300; 12 mos.

The project staff will study three related problem areas: (1) the reliability properties of operating systems; (2) the use of protection and dynamic decision-checking mechanisms to detect and isolate errors soon after they are committed, and to institute error-correcting actions; and (3) to extend models of secure information flow to include new applications, such as flow and error confinement in operating systems, and insuring confidentiality in data bases. Reliability in this context means immunity to error propagation and other illicit flows of information.

RAND Corporation; R. Stockton Gaines and Rein Turn; Research in Computer Security Evaluation and Enhancement; (MCS 7600720); \$59,900; 12 mos.

The research falls under three main headings:

The first area is an exploration of secureness in computer systems, its dependence on the structural and operational aspects of the system, the feasibility of quantitative evaluation of certain aspects of secureness, and the relation of these notions to the concepts of security that have been developed for protecting information stored in other forms.

The second area is research in enhancing the security of systems that are less than perfect, and for which enhancements would provide increased but still imperfect security.

The third area explores the use of encryption to increase the security of systems. Questions include how the cryptographic algorithm is set up properly for each encryption and decryption, and the difficulties that arise when the same information is encrypted more than once, or when more than one piece of information is encrypted using the same initial setting for encryption algorithm.

Stanford Research Institute; Norman R. Nielsen; Computer System Integrity Research Program; (MCS 7423774A01); \$104,500; 24 mos. (TQ)

The investigator will explore several means to enhance computer system integrity. The research will look at the issue of overall computer system integrity, where computer system refers to a simple batch computer, a multiaccess or multiprocessor system, or an entire network of computers as appropriate, and where integrity refers to the related and partially overlapping concerns of:

1. Security (protecting system integrity from compromise);
2. Audit (verifying the continued existence of system integrity, detecting anomalous behavior, and monitoring the correct application of proper processing);
3. Recovery (restoring system integrity and operability in the event of error, accident, willful damage, or disaster resulting in a loss of such integrity).

This award is a renewal of DCR-7423774.

Stanford Research Institute; Donn B. Parker; Computer Abuse Assessment and Control Study; (MCS 7601242); \$100,100; 12 mos.

The research will continue the development and expansion of SRI's file of case histories (currently containing records for 350 cases) and will computerize the file. The research will also develop a taxonomy of threats, and examine the technical and operational prevention and control techniques for computer abuse, the effects of advancing computer technology on white-collar crime, legal implications of computer abuse, the nature of computer abuse as white-collar crime, social loss from computer abuse, privacy violations, bureaucratic computer problems, and future aspects of computer abuse.

Two coordinated research efforts will be undertaken, one in law and the other in computer science, using field investigation, interviewing, case documentation, case analysis and application, and law and literature searching. A conference will be held, and progress reports and papers will be produced.

Stanford Research Institute; Donn B. Parker; Computer Abuse Problem Assessment; (MCS 7609183); \$18,000; 12 mos.

This grant is for preparing and reproducing several computer abuse and legal study documents based on research performed under GJ-44313; mailing 3,000 availability-of-reports letters and distributing 1,000 copies of the reports; and the preparation of a paper addressing the federal and state criminal code implications of computer abuse.

There are four major reports:

1. *Analysis of Threats to the Safe Use of Computers;*
2. *Computer Abuse Assessment;*
3. *The Criminal Law Aspects of Computer Abuse, Part One — State Penal Laws, and Part Two — Applicability of the Federal Criminal Code;*
4. *Legal Protection of Proprietary Rights in Software — Patents.*

State University of New York (Stony Brook); James B. Rule; Privacy Aspects of Personal Data Systems; (MCS 7520157); \$49,500; 15 mos. (Supplement, \$5,000 (TQ); total grant, \$54,500)

This study deals with a topical social policy issue involved with computing — the proliferation of bureaucratic documentation on private persons, and the impact of such documents on their privacy and autonomy. The study aims to show what kinds of personal documents Americans in typical social circumstances possess, how they obtain and use these documents and how computing technology affects both the reality of these things and the perceptions of that reality by the public. Information on these matters is to be collected through two sets of interviews. First, a *sample survey* of approximately five hundred persons, a representative selection of residents in several communities in Long Island, New York. Second, a series of *field interviews* with agencies involved in creating and using the personal documents which those in the survey possess.

The main questions to be addressed are: What are the most typical forms of personal documentation possessed by Americans? What are the usual effects of such documentation on the lives of those who possess it? What are the distinctive sociological properties of documents generated by or keyed into computerized systems? How does the computerization of personal information shape its treatment by organizations and its effect on the people to whom it refers? What are the implications for the design of computerized data systems?

Yale University; R. J. Lipton; Research on the Security of Computation; (MCS 7424193A01); \$15,600; 12 mos.

The principal investigators will collaborate with Professor Anita Jones at Carnegie-Mellon University in research aimed at developing a formalization of the concept of controlled dissemination of information from computer data bases. Their goal is to develop a formal theory that integrates understanding of security policies and protection mechanisms.

Human/Machine Interface

Institute for the Future; Jacques Vallee; An Investigation of Computer-Based Group Communication in Geoscience; (MCS 7505297A01); \$83,100; 12 mos.

This is a continuation of research previously supported under DCR 7505297.

The Institute for the Future will finish a two-year, large-scale test of the utility of computer conferencing in the context of the Office of Resource Analysis (ORA) of the U.S. Geological Survey. This environment reflects a need for group communication and management planning tool; it is also representative of a wider class of applications in government and business.

The primary goal of the study is to observe, document, and quantify the long term effects of computer conferencing systems in an operating environment of a research organization. More specifically, the objectives are:

1. To conduct and monitor several conferences on topics covering a representative range of tasks, including:
 - Coordination of data-base resource utilization;
 - Support of the design of the National Geothermal Energy Data Bank;
 - Mineral resource analysis and reserve estimates.
2. To provide information useful for the use and design of computer-based teleconferencing systems in real-world environments.

Institute for the Future; Jacques Vallee; Field Testing of Computer Conferencing; (MCS 7505298A01); \$83,700; 12 mos.

This project entails an expanded investigation of social, managerial, and economic aspects of computer conferencing. The work will center on the issues of teleconferencing research, including management, analysis, and social assessment of teleconferencing systems. It will also include a workshop in Washington, D.C., to review the practical experience of the FORUM project as well as that of other conferencing projects.

Massachusetts Institute of Technology; Roy Kaplow; Enhanced-Input Terminal; (MCS 7411962A01); \$50,800; 12 mos.

This is the second year of a project to design, construct and evaluate the use of a new type of computer terminal. The project is aimed at providing major new degrees of freedom for touch-type input, especially for on-line use of interactive computer programs. The terminal consists of an integrated system of hardware and software. The primary input device is a video-displayed, "cross-wire", touch-sensitive panel, and a video unit is also used for output display. Both of these are supported by 256K-bit page-refresh memories, written (and read) directly by the PDP-11/40 processor which implements the software logic in the prototype machine. The *Enhanced-Input Terminal* allows the user to define an essentially infinitely large set of symbols and an infinite variety of "keyboard" formats. Chord inputs (that is, simultaneous, multiple-key combinations) are also supported.

New Jersey Institute of Technology; Murray Turoff; Research on Computer-Based-Conferencing Systems; (MCS 7616598); \$95,900; 12 mos.

This project entails research on a computer language for tailoring human communication structures that are to be executed via computer terminals. The goal of the project is to explore the design requirements for a computer language that may be utilized by social scientists and others concerned with structured human communication processes (e.g., Delphi Designers, Information Systems Designers, etc.) to design systems for group communications.

Southern Illinois University; William A. Fetter; A Human Figure Computer Graphics Development for Multiple Applications; (MCS 7615400); \$30,000; 12 mos.

This Computer Graphics project is for the development of anthropometric tools that are useful in a number of applications by means of a system of figures fitted to different working scales. The need for a unified and generalized capability arises from the growing number of computer simulations of the human body and its functions, the graphic qualities sought in their presentation and the improved graphic communication capability needed to reach both specialists and laymen.

The problem addressed is how to design a system of comprehensive computer programs and data bases which are suitable for a large spectrum of applications both specialized and generalized, and for other users seeking alternative graphic techniques. The objectives are to design data bases with consistent qualities of imagery, plan figures for a number of levels of detail and produce demonstration applications in concert with prospective research users.

The tasks involve the integration of the eight-step approach and the visual module system with new human figure data base applications. The quarterly schedule will include (1) organization, (2) data acquisition, and (3) computation.

University of Virginia; John L. Pfaltz; Surface Networks for the Study of Graphical Data; (MCS 7413353A01); \$16,000; 12 mos. (Joint support with Theoretical Computer Science - total grant, \$30,000; 12 mos.)

Surface networks are directed graphs analogous to the network of ridges and courses connecting the peaks, passes (saddies), and pits of geographic surfaces. This project will explore these networks as a tool for investigating and describing not only geographic surfaces, but general functional surfaces occurring in a wide range of disciplines using computer graphics.

Studies and Colloquia

Colorado State University; G. R. Johnson; Information Processing for Optimization of Energy Utilization in Structures; (MCS 7503578A01); \$67,000; 12 mos.

This project is a continuation of Grant DCR 7503578. This project deals with research on new control systems and algorithms for the efficient management of a building's energy budget based upon information processing theory and optimal control concepts. The project consists of the verification of a dynamic system simulation model, the determination of the optimal operational policies, the development of efficient algorithms and the experimental implementation of a test system.

Los Alamos Scientific Laboratory; N. Metropolis; International Research Conference on the History of Computing; (MCS 7413193A02); \$8,200.

A research conference on the development of the digital computer will be held during the summer of 1976 at Los Alamos Scientific Laboratory. The conference will call together most of those remaining scientists who were involved with the early development of the digital computer, and historians of science. The meeting will serve three purposes. It will encourage research in the history of computers; it will record "living history" in the form of discussions among the pioneers in electronic computers; and it will provide computer scientists with an insight into the processes of history of science.

New Jersey Institute of Technology; Murray Turoff; Computer Based Workshop on Future Research in Computer Based Conferencing; (MCS 7680514); \$35,900; 12 mos. (TQ)

The objective of this workshop is to develop and delineate concisely the key areas of research requiring and deserving exploration over the next five years in the area of computerized conferencing. Computerized conferencing is defined as the use of interactive computer systems acting as a direct facilitator of human group communication via the incorporation of protocols and structures tailored to aid the objective of the communications process.

The effort will utilize approximately thirty individuals who have directly or indirectly been involved with this field of research and will focus on potential endeavors in the following three areas:

1. Design and Implementation;
2. Application and Impacts;
3. Policy and Resources.

The workshop will take place over a computer conferencing system based at the Newark Institute of Technology.

Princeton University; Bruce W. Arden; Computer Science and Engineering Research Study; (MCS 7680254); \$89,300; 12 mos. (TQ)

A major study of the present state and future potential of computer science research will be continued. The study committee will attempt to define the relevant subfields of computer science, and to analyze how and where research is conducted in these subfields. They will also examine the important unsolved problems and seek those which appear to be both significant and solvable in the foreseeable future.

This award is a renewal of DCR-7515491.

Public Systems Evaluation Incorporation; Kent W. Colton; Exploratory Workshop on Long-Term Research for the Policy Impact of Computer-Based Electronic Funds Transfer Systems; (MCS 7624416); \$13,100; 9 mos. (TQ)

A workshop will be held on the general topic of establishing a research agenda for studying the impact of Electronic Funds Transfer Systems (EFTS). Top experts around the country will be brought together, along with the research staff of the National Commission on Electronic Funds Transfer, to discuss long term research needs. Particular attention will be paid to the technological issues underlying widespread EFTS implementation.

University of Texas (Austin) John J. Allan; IFIP International Working Conference on CAD Systems; (MCS 7519378); \$22,600; 12 mos. (Supplement, \$2,000 - total grant, \$24,600)

This project is a working conference on Computer-Aided Design (CAD). Papers, invited from a list of people specified by an IFIP committee, will cover CAD research in Executive Systems, Command Languages, Data Structures, and Hardware.

The meeting, sponsored by the Working Group 5.2—Computer-Aided Design of the IFIP Technical Committee 5 on Computer Applications, will be a working conference to probe in depth the above aspects of CAD. The goal is to produce a compendium of well-discussed papers that will form a state-of-the-art discussion of the subject.

The meeting is to be held on Thursday, Friday and Saturday, February 12, 13, and 14, 1976 on the campus of the University of Texas at Austin.

Data Bases

University of Florida; Stanley Y. Su; Application Program Conversion Due to Data Base Changes; (MCS 7610075); \$40,000; 12 mos.

Advancement in hardware and software technologies and changes in the use environment of data base management systems often require that the data bases and their associated application programs be translated and converted in order to take advantage of newer technologies and new application needs. Research must be conducted to find efficient techniques for automatic or semi-automatic application program conversion, so that the expense and time involved in manual rewriting of application programs can be avoided.

This research aims to: (1) investigate the relation between data base translation and application program conversion, (2) identify the program conversion tasks and their possible automation, (3) study the techniques for solving the conversion problem through computer-aided analysis of application programs, (4) investigate the data mapping operators useful for data base translation and their effects on program conversion, and (5) study the techniques for converting sub-language statements and for analyzing the host language programs.

Harvard University; A. H. Schmidt; Geographical Information Systems; (MCS 7602528); \$80,400; 12 mos.

The research project has two goals:

1. To create a regional information system based on a data structure which incorporates spatial topology. The basis for the system will be a chain file with neighborhood pointers for each chain. A chain is a set of points with nodes at their ends and information about joining chains and bounding polygons. A set of chains defines a set of polygons and/or lines. The system is designed to allow for a series of operations merging and comparing geographic entities and displaying the results cartographically.
2. To implement this system in an interactive mode. The interaction takes place mainly in the creation of display files by accessing a data base.

University of Maryland (College Park); Edgar H. Sibley; Structured Information Systems; (MCS 7603142); \$45,900; 12 mos.

There are several different approaches which have recently been suggested for dealing with the specification and design of large-scale information systems and, at the same time, influence the independence between data and program (so-called "data independence"). These systems variously attempt to separate the concepts of information, data, and the storage of instances of

the data. At the same time, they tend to produce modular systems by using a top-down approach to provide a structured design.

This research is intended to:

1. Investigate three of these approaches in order to determine the similarities and differences in the approaches;
2. Further develop methodology in at least one of these systems at the infological level;
3. Consider the datalogical level in terms of various storage and retrieval efficiencies.

Purdue University; S. B. Yao; Design Modeling and Performance of Data Base Systems; (MCS 7616604); \$45,500; 24 mos. (TQ)

This research concerns the selection of appropriate data base structures and access methods for the construction of large data bases within on-line information systems. The project will continue and extend the Hierarchical Access Model developed for the optimal selection of data base structures and access paths. In particular, the following problems will be addressed:

1. Extend the Hierarchical Access Model to improve its accuracy in representing new types of data base structures;
2. Extend the applications of the Hierarchical Access Model to include both physical and logical data base design;
3. Apply the model for developing data base performance measurement tools;
4. Use performance measurement, analysis and evaluation techniques to validate the model;
5. Use the model to optimally select data base structures and access paths.

Networking

Massachusetts Institute of Technology; Michael Athans and Robert Gallager; The Dynamics of Data Networks; (ENG 7624447); \$17,300; 12 mos. (Joint support with Engineering - total grant \$92,300; 12 mos.) (TQ)

This research program is aimed at developing fundamental understanding of the dynamic behavior of data communication networks. Specifically, further work on the following problem areas will be pursued:

1. Protocol Information in Data Networks;
2. Routing Algorithms and Associated Control Problems.

New important problems that will be addressed include congestion control network design with limited state information at the nodes of the network, and link and node failures.

This award renews the research supported under NSF Grant ENG 7514103.

University of Michigan; Kan Chen; Computer Based Conferencing Experiment at 2nd Annual Technology Assessment Congress; (MCS 7622014); \$24,400; 12 mos. (TQ)

The Second Congress of the International Society for Technology Assessment (ISTA), meeting in Ann Arbor in October of this year, provides a unique opportunity for examining contributions of teleconferencing to a multidisciplinary conference extended to an international community. The University of Michigan, with the endorsement and assistance of the ISTA Congress Program Committee, will conduct an experiment which will demonstrate and assess the significance of the contribution of computer-based communications to technical communications in association with this international professional meeting.

Computer-based conferencing will be experimented with as a communications tool during the conduct of the Congress, extending discussions to nonattending members of ISTA. In addition it will be used directly to support the activities of the Congress.

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